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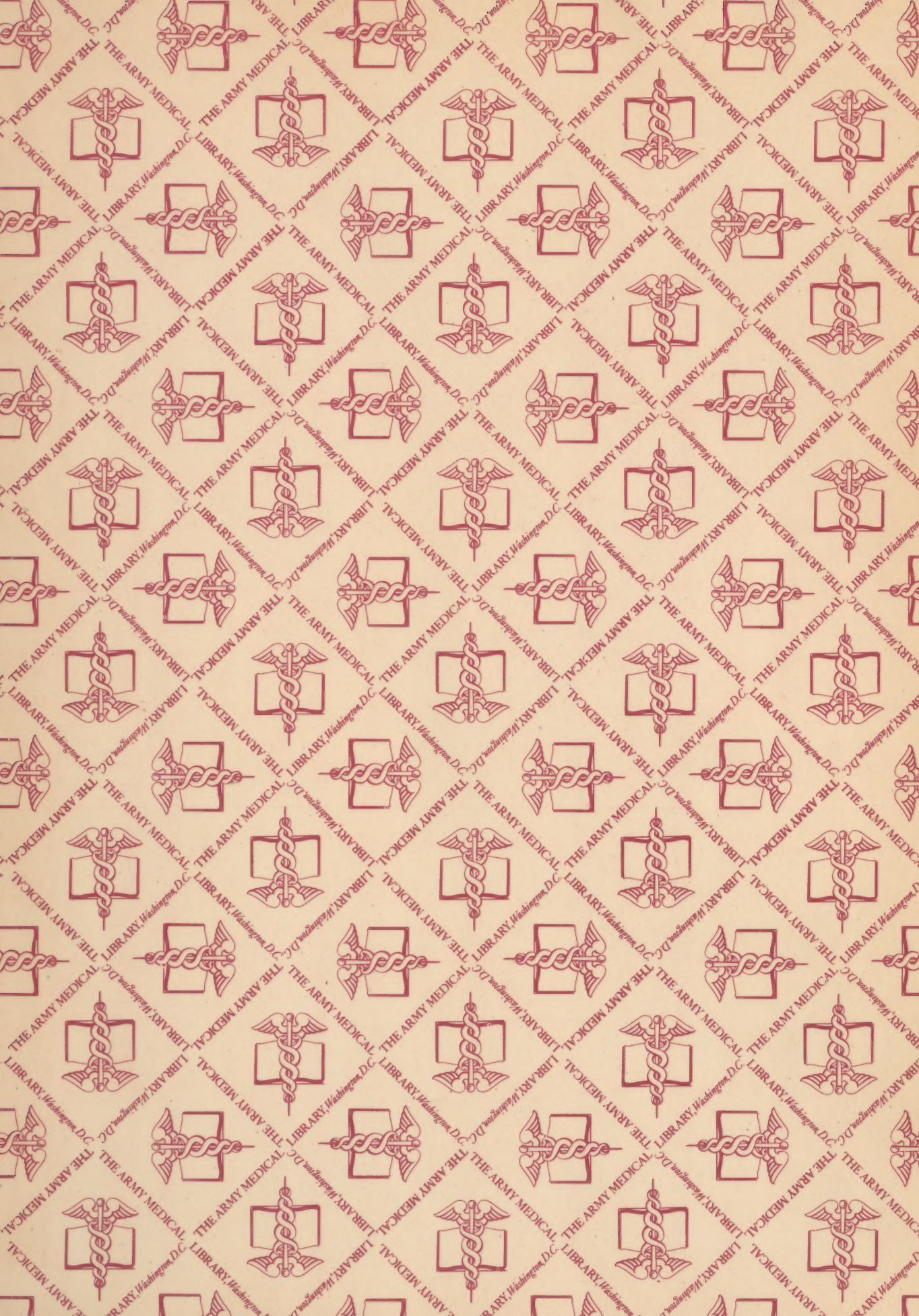


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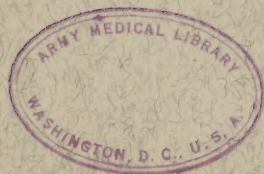
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CLIMATIC RESEARCH LABORATORY



*The Development of the Testing Techniques
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Climatic Research Laboratory*

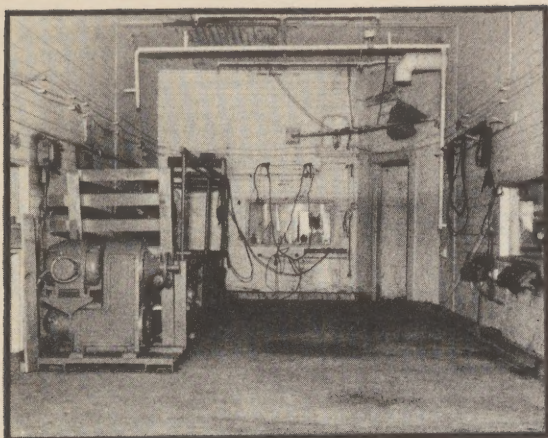


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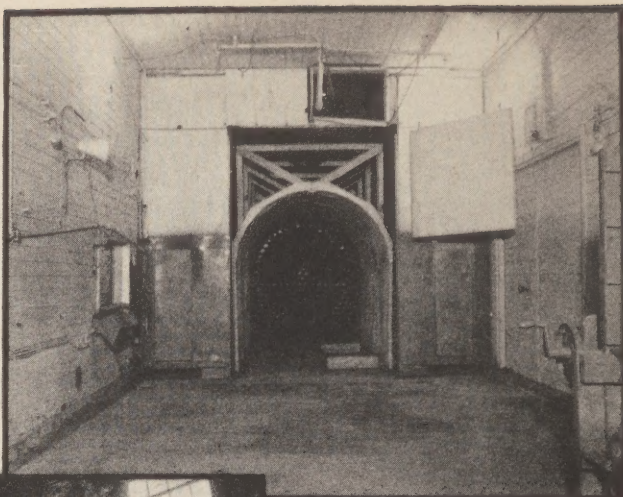


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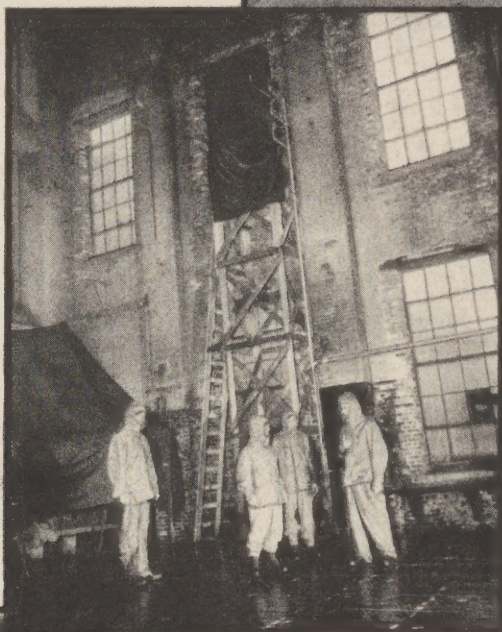
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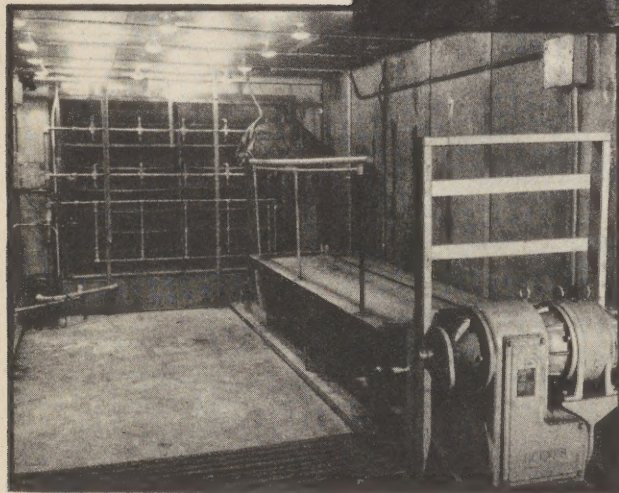
**TREADMILL
COLD ROOM**



**WIND TUNNEL
COLD ROOM**

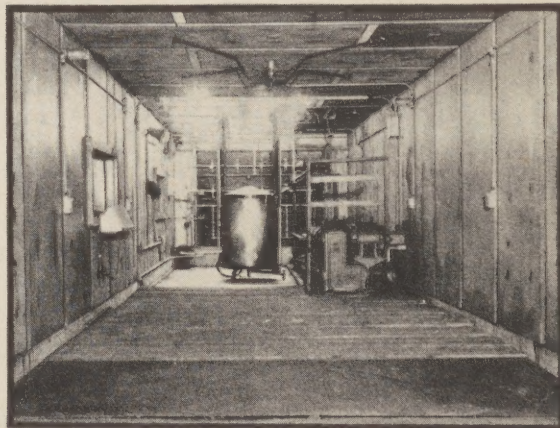


**RADIATION SECTION
JUNGLE CHAMBER**



RAIN COURT

**RAIN AREA
JUNGLE CHAMBER**



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Army Service Forces
U.S. Quartermaster Corps
CLIMATIC RESEARCH LABORATORY
Lawrence, Massachusetts

10 May 1946

This report has been prepared by Lt. Richard E. Morris,
CSC. The Development of the Testing Techniques and Procedures Utilized at the
Capt. William G. Silver, Climatic Research Laboratory

APPROVED:

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SUBMITTED TO:

Brig. Gen. W. H. Middleswart
Military Planning Division
Office of The Quartermaster General
Washington, D. C.

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Army Service Forces
Quartermaster Corps
CLIMATE RESEARCH LABORATORY
Lawrence, Massachusetts

10 May 1946

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The Development of Testing Techniques
and Procedures Utilized at the
Climate Research Laboratory

FORWARDED TO:

Mr. Don W. G. Middleman
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MAY 4 - 1949

CONTENTS

INTRODUCTION

Page

I. PRINCIPLES OF PHYSIOLOGICAL DETERMINATION OF THERMAL INSULATION

This report has been prepared by Lt. Richard O. Morris, QMC. Technical advice and assistance have been supplied by Capt. William L. Goddard, QMC, and Mr. Rollo G. Silver.

IV. EVALUATION OF HOT-CLIMATE CLOTHING

APPROVED:

VI. WATER-IMPERMEANT TESTS FOR CLOTHING

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VII. DETERMINATION OF MOISTURE PERSPIRATION IN CLOTHING

VIII. DETERMINATION OF MOISTURE DISPOSITION AND UPTAKE

IX. PHYSICAL MEASUREMENTS OF MILITARY CHARACTERISTICS

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CONTENTS

	Page v
INTRODUCTION	v
I. PRINCIPLES OF PHYSIOLOGICAL DETERMINATION OF THERMAL INSULATION	1
II. PHYSIOLOGICAL METHODS FOR THE DETERMINATION OF THERMAL INSULATION	8
III. PHYSICAL METHODS FOR THE DETERMINATION OF THERMAL INSULATION	27
IV. EVALUATION OF HOT-CLIMATE CLOTHING	41
V. MEASUREMENTS OF MANUAL DEXTERITY PROVIDED BY HANDGEAR	48
VI. WATER-REPELLENCY TESTS FOR CLOTHING	52
VII. DETERMINATION OF MOISTURE PENETRATION IN FOOTGEAR	61
VIII. DETERMINATION OF MOISTURE DISPOSITION AND UPTAKE	64
IX. PHYSICAL MEASUREMENTS OF MILITARY CHARACTERISTICS	68

ILLUSTRATIONS

Test Facilities	<u>Frontispiece</u>
	Following Page
Testing in the Cold Room	20
Cross Section and Top View of Guarded Flat Plate	28
Guarded Flat Plate with Thermocouples	28
Guarded Flat Plate with Fabric	28
Electrical Circuit of Guarded Flat Plate	28
Guarded Flat Plate - Uncovered	30
Guarded Flat Plate with Bag, Sleeping, Mountain	30
Guard Ring Flat Plate No. 2 - Thermocouples	31
Guard Ring Flat Plate No. 2 - Cross-Section	31
Guard Ring Flat Plate No. 3 - Cross-Section	32
Wooden Frame for Guard Ring Flat Plate No. 3	32
Guard Ring Flat Plate No. 3 - Thermistors on Test Section	33
Guard Ring Flat Plate No. 3 - Thermistors on Bottom Plate	33
Guard Ring Flat Plate No. 3 with Bag, Sleeping, Mountain	33
Guard Ring Brass Cylinder - Cross Section	35
Guard Ring Brass Cylinder	35
Guard Ring Aluminum Cylinder - Cross Section	37
Guard Ring Aluminum Cylinder	37
Guard Ring Aluminum Cylinder with Fabric	37
Bronze Foot	39
Bronze Foot with Ski Sock	39
Testing in the Jungle Chamber	46
Tests for Manual Dexterity	49
Tests for Water-Repellency	54
Tests for Moisture Penetration in Footgear	62
Tests for Moisture Disposition and Uptake	66

INTRODUCTION

From the time of activation of the laboratory until the cessation of hostilities, methods for the evaluation of clothing and equipment were frequently devised. It is no exaggeration to state that the greater part of the experiments conducted at this laboratory utilized new techniques. Some of the test directives required methods which had not been previously standardized; in other instances, the items subjected to test had been specially constructed for new purposes.

In time of war, it was not possible to direct attention to all aspects of a problem; only the most important objectives were considered. The techniques employed, therefore, were created to produce desired results with minimal expenditure of time and manpower. Furthermore, there was no opportunity to standardize many of the procedures. At the conclusion of this period, it is appropriate to consider the techniques and, by utilizing the experience acquired, to standardize the methods of testing.

This report presents the first phase of an investigation initiated for such a purpose; all data relating to previous test procedures have been collected and classified according to type of test item. The sources of these data, available in the archives of this laboratory, were:

Provisional Reports

Numbered Reports

Memoranda to OQMG

Minutes of conferences and staff meetings.

Analysis of this information supplies the background necessary for a comprehensive study of test procedures. Furthermore, this report provides a work of reference which will be useful to other organizations and is, as well, a contribution to the investigation presently being conducted by the Committee on Standardization of Test Procedure.

WILLIAM R. CHRISTENSEN
Captain, MC
Commanding

CHAPTER I

PRINCIPLES OF PHYSIOLOGICAL DETERMINATION OF THERMAL INSULATION

Although physiological tests of thermal insulation require methods appropriate to the nature of the test items, ten principles have served as the basis for all test plans. Constant conformity to these principles has insured proper control of the tests as well as the acquisition of data which are valid and capable of statistical analysis. Since these principles are fundamental to the greater part of the experiments conducted at this laboratory, it is proper to summarize them before presenting detailed descriptions of the test procedures:

(1) Tolerance time and skin temperature data are utilized in physiological testing. These two criteria are closely inter-related. For a given subject, when the exposure is terminated at his request (subjective feeling of intolerable pain) the skin temperature of his feet (usually the toes) is close to the critical level characteristic of this subject. This laboratory prefers a separate statistical analysis of each of these types of data rather than a calculation of a 90° to 60°F. cooling time (Harvard Fatigue Laboratory) or an index of °C./minute fall in skin temperature (National Institute of Health.)

The significance of tolerance time has been analyzed in the Provisional Report for 13 November 1943:

Tolerance time is a very useful unit of measure in the studies pursued in the cold room. It may be applied to any item of clothing, handgear, footgear or sleeping gear. It is the capacity of an item to perform its function expressed in units of time.....

In an item of clothing or other gear that provides thermal insulation, tolerance times have been used as the limit of usefulness under specified conditions.

Woolen mittens with a windproof shell may be taken as an example. If a subject were to dress in a complete Arctic outfit with face mask and the best mukluks or felt shoes available and sit at rest without moving the hands at an exposure temperature of minus 40°F., in order to simulate duty on a look-out post, the hands would become uncomfortably cold within 30 or 45 minutes. After 60 minutes had passed the hands would become painful and by the end of 90 minutes some change in state must be provided, otherwise, the fingers will become frostbitten. It can be assumed that the tolerance time has been reached for the pair of mittens at the exposure temperature specified under the conditions of activity provided, which in this instance is rest.

For the sake of emphasis it should be restated that the above-specified tolerance time of 90 minutes applies only to a subject at rest, wearing clothes as enumerated, and at an exposure temperature of minus 40°F. If any of these conditions is modified, tolerance time is altered. If the subject is simulating sentry duty and is slowly walking about, the breakdown point of the mitten becomes longer than 90 minutes, possibly 120 minutes. If the subject engaged in physical activity, sufficiently strenuous to simulate a soldier in an engineer battalion building a bridge, or a soldier pulling a sledge in the snow, the mitten may provide sufficient protection for several hours and the tolerance time will be increased to 4 or 6 hours.

A second factor which increases tolerance time for a particular item is the insulation provided for the remainder of the body. The human body should be considered as a stove capable of generating considerable heat but the arms, legs, and head are conducting the heat away faster than it can be produced. If the loss of heat through the feet can be reduced, the covering over the remainder of the body including the hands remaining the same, the tolerance time for the mittens will be increased.

Finally, the third controllable variable is exposure temperature. If the mitten combination provides protection for 90 minutes at rest with the clothing specified at minus 40°F., the breakdown point will come in a shorter time at colder temperatures, 80 minutes probably at minus 50°F., and at a longer interval, 100 minutes, at 30°F.

There are other factors which influence tolerance time in addition to the degree of exercise, clothing

worn over the remainder of the body and exposure temperature. These factors are more difficult to recognize and evaluate and for practical purposes may be neglected.

In this discussion, it has been tacitly assumed that at subzero temperatures, tolerance times must be taken into account since no clothing or other gear is adequate for indefinite periods of time under all conditions. Throughout the exposure, from the beginning of the experiment until the breakdown point, the body is slowly losing heat and the margin of reserve becomes smaller. Even though it may appear that the mittens break down at 90 minutes when the hand becomes unbearably cold, this statement does not do justice to the facts. The mitten is providing only relative protection throughout the exposure period. Changes may be introduced to lengthen or shorten the tolerance time but unless something is done to prevent inevitable loss of body heat, there comes a time when intolerance appears.

Of course, the only means of preventing further loss of body heat is removal to a warmer environment, such as a heated tent or a shelter. Exercise and additional clothing are but temporary expedients and do not prevent further heat loss or restore the heat already dissipated.

It is reasonable to inquire how reproducible are tolerance times. In trained subjects, accustomed to the cold room, the results from subject to subject and from day to day are consistent and satisfactory. Some subjects have consistently longer tolerance times and appear to be more resistant to the cold than the average. Other subjects have shorter tolerance times and appear more susceptible to the cold. The majority of subjects tested show neither a resistant nor a susceptible reaction to the cold and fall in the average group.

Because tolerance times for a given item of clothing under controlled conditions give reproducible results, the data obtained may be transposed into performance in the field, either maneuvers or combat. If it can be stated to the Commanding General that this mitten combination keeps a soldier from being frost-bitten for a 90-minute period at rest at minus 40°F., it is a tangible statement. It is based solely upon subjective evidence, but the expression is in everyday understandable units. If tolerance times for all items of clothing are known, it is of great help in planning the total clothing for a soldier and in approximating the possibilities and limitations of performance in the field.

The significance of skin-temperature data was investigated in extensive series of skin-temperature measurements at all exposure temperatures. A seventeen-lead thermocouple harness was utilized in this study. An analysis of the observations disclosed that the skin temperature of various parts of the body did not vary sufficiently to justify as many as seventeen separate temperature points. The temperature response to cold may be classified into three groups. In this study the hands and feet exhibited the maximum decrease. The coldest temperature recorded for the fingers was plus 34°F., and the coldest temperature for the toes was plus 44°F. The thighs, upper arm and the chest are in a second group: in only one instance was the skin temperature of these parts below plus 80°F. Finally, skin temperatures over the abdominal wall and kidney region revealed little variation: a significant number of these measurements were above plus 90°F.

Since temperatures on the trunk vary only slightly, it is reasonable to assume that such skin temperatures would rarely indicate differences in thermal insulation. On the other hand, since the toe and finger temperatures varied over a wide range, they serve to indicate the clearest and most obvious differences in insulation.

(2) Subjective reactions must be obtained. They supply a routine check on the mechanical efficiency and accuracy of the thermocouple technique as well as information relating to subjective criticisms, comments and preferences. These subjective reactions must be obtained in accordance with standardized and controlled interview procedure.

(3) The items being tested must bear the maximum strain of thermal insulation. There is little value in exposing men in the Cold Room for a test of footgear if their hands become unbearably cold first; the test then

becomes one of handgear, not footgear. To prevent this, the subject must be overdressed on those parts of the body in which the physical breakdown (i.e., becoming unbearably cold) is to be forestalled as long as possible.

(4) A differentiation must be made between tolerance and adequacy.

If a subject is able to spend 6 hours in a sleeping bag at a given temperature, he has tolerated the bag for this period. If he has been comfortable throughout the period and has been able to sleep most of the time, the bag also can be considered adequate. On the other hand, if the subject has shivered and has been too cold to sleep, the bag cannot be considered adequate even though it was tolerated for the 6 hours. If this situation had occurred in the field, the efficiency of the combat soldier during the following day would have been considerably reduced. The bag, therefore, would be inadequate in the mission for which it was devised even though its tolerance time was satisfactory.

(5) The results obtained from morning tests must be treated separately from those obtained in afternoon tests. A quotation from the Provisional Reports states this principle clearly:

There are several differences between morning and afternoon exposures. The mean tolerance time is more than 20 minutes longer in the morning than in the afternoon....In addition to the tolerance time, the skin temperature of the fingers at the onset of the exposure was more than 10°F. higher in the afternoon than in the morning. This is consistent with previous findings in footgear. The rate of cooling, however, in the afternoon was considerably faster than in the morning and the threshold for pain was at a considerably higher level. An alternate explanation is an anesthetic affect (sic) of the cold in the morning with greater tolerance from a lower threshold. (Provisional Report, 19 October 1943)

(6) When successive exposures are contemplated, a sufficient warming-up period must be allowed. After a short warming-up period, the

tolerance times of successive exposures are greatly reduced and the skin temperatures rapidly drop to levels as low or lower than the comparative temperatures of the previous exposures.

(7) Data must be analyzed with proper weight given to all extraneous influences. Physiological testing, contains variables which cannot be controlled but which can be recognized and noted. A few of the variables which must be considered are as follows;

(If experiments are properly planned and executed these variables are so controlled that they do not influence the test results.)

- (a) Activity of the wearer
- (b) Individual variation between subjects
- (c) Physiological state of the subject
- (d) Body clothing
- (e) Moisture and dirt in socks
- (f) Variation in air temperature and wind velocity
- (g) Variation in tightness and fit of the footgear

(8) Each test problem must be completely and thoroughly analyzed before the proper test plans can be prepared. An example of incomplete analysis is cited in the following quotation:

Certain limitations on the procurement of the thermal insulation data requested for the Boot, Navy, Experimental were imposed by the nature of the boot itself. It was requested that the insulating value of spun glass be investigated and that certain types of footgear be used as a standard of comparison. These suggested types of footgear, however, were constructed from diverse materials, were varied in design, and, in some instances, commonly were worn with different sockgear combinations. Thus, any differences in thermal insulation were the result of many factors, only one of which concerned the value of the insulating material used in the construction of the boot.

(Provisional Report, 12 September 1945)

(9) The detailed procedure of the test must be planned so that the results will provide the information desired and data capable of proper statistical analysis. A test crew must be chosen which is a multiple of the number of items to be tested, and a sufficient number of days or half-days must be assigned to the test to provide one day or half-day of testing for each item to be tested. All items are used on each day by an equal number of men, and all men progress through the items in an orderly fashion so that each man wears each item. All other conditions are kept as constant as possible for the duration of the test. In this manner data are obtained which eliminate or account for individual variations between subjects or Cold Room conditions, since each item has been exposed each day. The above represents the theoretically perfect procedure for any comparative experiment.

(10) Valid test results in physiological testing are based upon the intelligent cooperation of the test subjects. Every effort must be directed toward maintaining a high level of morale and initiative. Objectives of each test program must be explained to the subjects. It should be emphasized that theirs is an important, integral part of the total program.

CHAPTER II

PHYSIOLOGICAL METHODS FOR THE DETERMINATION OF THERMAL INSULATION

In addition to the principles applicable to all physiological tests of thermal insulation, particular methods of testing are appropriate to specific classes of equipment. This laboratory has, for instance, developed standardized procedures for sleeping-bag tests, for footgear tests, and for handgear tests. Nevertheless, owing to the requirements of the test directive, these procedures must often be modified. In order to illustrate the variations in testing techniques as well as the development of the procedures, the tests for each class of equipment are discussed in separate sections.

Sleeping Gear

Soon after the Laboratory was activated, it was decided that all sleeping-bag tests would be conducted during a period of 6 hours. Results of tests conducted during shorter periods were misleading because the time was not sufficient to permit a breakdown of the sleeping bag.

The initiation of sleeping-bag tests introduced a difficulty which was soon mastered. An account appears in the Provisional Reports:

In planning this experiment we encountered one difficulty that had not been foreseen, but if we had thought about it we should have visualized the possible hazards. In the Cold Room there is a thick cement floor. It is slow to come into equilibrium at subzero temperatures after it has been warmed, such as over the weekend. Also, we had not anticipated the sluggishness with which it would gain heat after it had been at a low temperature. In order to avoid conductance of heat from the body to a colder floor than the room temperature, or vice versa, we have built a false wooden floor in the Cold Room to be used for sleeping bag experiments.
(Provisional Report, 23 August 1943)

Later studies relating to the heat loss through the sleeping bags contributed other information in addition to tolerance times and toe temperatures. For this work a blanket with 32 thermocouples attached at various points was constructed. All exposures were made with the subject encased in the sleeping bag and lying on a canvas litter with the thermocouple blanket between the litter and the bag. The poorer sleeping bag permitted more heat to escape, a fact which was reflected in higher temperatures recorded on the blanket.

During the early Spring of 1944, attention was devoted to a study of the soldier sleeping in wet clothing. Standard procedure (tolerance times and toe temperatures) was utilized, but additional data were obtained by weighing the clothing and the subjects before and after exposure. These data furnished additional information on the evaporative loss of heat from the body of the subject. A detailed description of this test procedure follows:

Nine soldiers entered the cold room on three successive days. Each man slept in a wool batt sleeping bag each day for 6 hours or until unbearably cold. Each man slept in dry clothes in a bag covered with a water-repellent case one day, in wet clothes in the same bag covered with a water-repellent case another day, and in wet clothes in the same bag covered with a water-impermeable case on the third day. The schedule was arranged so that three men slept in each combination of wet or dry clothes and repellent or impermeable cases each day. Tolerance times and great toe temperatures were measured. Bags were weighed before and after each exposure. The wet clothes were weighed before and after each exposure in order to determine the net amount of evaporation that occurred.

The clothes for this experiment were weighed, soaked wringing wet in water and then wrung out and let dry until the weight of water left in the clothing equalled the original weight of the clothing. They were then placed in waterproof bags, and sufficient water was added from time to time as necessary to keep the weight of

water in the clothing equal to the original weight of the clothing. Wool clothes wet with this amount of water feel decidedly damp, but do not drip.
(Provisional Report, 13 March 1944)

In another phase of this test, an artificial rainfall was devised for the Cold Room. This study, distinct from the study of the waterproofness of the sleeping-bag case, related to the effect of moisture upon the thermal insulation of the sleeping bag. The test was described as follows in the Provisional Reports:

Six soldiers were studied in the coldroom at an exposure temperature of plus 30°F. Each subject rested in two wool sleeping bags wearing basic clothes that might be issued for combat at such a temperature. Of these, two soldiers used no protective case about the sleeping-gear; two used one case, water-repellent, Bag, Sleeping, Mountain, and two used an experimental relatively water impermeable case. The soldiers were so placed in the cold room that they were exposed to the direct effect of the atomizers which delivered a heavy mist into the room by means of compressed air. The atomizers were operating throughout the entire period of exposure. A heavy, freezing mist was produced which thoroughly wet every object in the cold room. The wind velocity was approximately 3 mph. and was turbulent.
(Provisional Report, 31 January 1944)

The procedures outlined above generally prevailed throughout the remainder of the testing period, but another variation appeared in the Fall of 1945. Until this time, tests had been designed to provide comparative data; however, information was desired concerning the lowest ambient temperature at which a sleeping bag would provide the required amount of rest. For this test, the subjects were exposed at an ambient temperature higher than the presumed critical temperature. In succeeding exposures, the ambient temperature was reduced until the critical temperature had been determined.

Footgear

Since there were no thermocouples or potentiometers available to record

the toe temperatures when the Laboratory was activated, initial tests were restricted to subjective reactions. Adequacy was determined by relative comfort at the conclusion of 3 hours at rest in the Cold Room. The period required for the foot to become cold was tabulated. With the acquisition of proper equipment, objective data were obtained and the footgear testing continued, utilizing standardized procedures of toe temperatures and tolerance times.

One of the first studies investigated the ability of the Laboratory's staff to reproduce data. In June, 1943, the following report was submitted:

Among other matters we wanted to learn whether we could repeat a cold experiment several weeks later with same footgear, at same exposure temperature and get comparable data. Early in June we had tested the above-mentioned footgear and had drawn tentative conclusions regarding the various items. Another reason for studying service shoes and overshoes at this time was to note how the subjects reacted to this gear after concentrating upon shoe-pacs. In regard to the first inquiry it may be stated that the thermal insulation data were essentially the same as those collected 3 weeks previously. The breakdown of the several footgear combinations came on at the same temperature and the several criticisms of the gear were reiterated.

(Provisional Report, 28 June 1943)

The procurement of a Cold-Room treadmill in the Spring of 1943 facilitated studies of fit and comfort in footgear. The Provisional Report of 29 June 1943 outlines this procedure:

Observations were obtained in the cold chamber and on a field trip. The cold chamber was kept at plus 10°F. through the morning and at zero F. in the afternoon. The subjects were clad in pile garments so that their bodies would be warm and that breakdown from the cold, if any, would come in the feet first. The subjects rested sitting as long as possible before they exercised on the treadmill. The length of time that they remained at rest before their feet became unbearably cold was considered the most significant datum. Our primary concern in the

Cold Room experiments was the ability to protect against the cold; of secondary concern was design and comfort, particularly in comparison with the shoepac. There were 3 pairs of Hood boots, 3 pairs of U.S. Rubber and 2 pairs of Goodyear worn in the cold chamber.
(Provisional Report, 29 June 1943)

In July, 1943, the necessity for minimizing activity in footgear testing became apparent during a sockgear test in which sentry duty was simulated. In that test, the subjects were required to stand during the exposure period with boot movement restricted within a 14-inch square. Despite the relatively small amount of activity, tolerance times for the standing soldiers were longer than those for the soldiers sitting at complete rest.

Also, during July, 1943, a variation in footgear testing was introduced. The subjects, clothed in a warm sleeping bag, extended one foot through a pile-lined sleeve in the bag, exposing the foot to the ambient temperature. As in the standard procedure, comparative tolerance times and toe temperatures were determined for different types of footgear worn on the exposed foot. Fundamentally, this technique was only another method of overdressing the part of the body not under test, but it possessed the advantages of requiring less clothing for the subjects and, consequently, consuming less time in preparation. Following is a description of the test procedure:

Three experimental subjects participated. A warm sleeping bag (No. 203) was designed so that a sleeve of alpaca pile protruded from the lower right portion of the bag. This allowed the right foot and ankle to be extended from the bag, the left foot meanwhile remaining within the bag. A sleeping bag was used because we wanted to reduce loss of body heat to a minimum and have the exposed member be the main source of heat loss. Both feet were clothed alike, the only difference between right and left foot was the position. The right foot being outside and the left foot inside the sleeping bag. Experiments were conducted with one and two pairs of ski socks, with and without a shoepac. The basic clothing

was 50-50 underwear, the basic sockgear was cushion-sole, wool socks, one pair. Thermocouple measurements were taken throughout the exposure period. The subjects sat in a chair during the exposure since we were interested in duplicating the wearing of clothes rather than any information about sleeping bags per se.
(Provisional Report, 23 July 1943)

In October, 1943, a test technique for footgear which was used extensively in later months was reported:

On two recent days, mukluks and felt boots were studied at an exposure temperature of minus 40°F. On each of two mornings the subjects wore either mukluk or felt boot on both feet. In the first afternoon exposure the subjects wore one boot on one foot and another boot on the other foot. These experiments were conducted for the following reasons:

1. To determine whether the right and left foot might be used for separate but similar experiments.
2. To determine whether there was a significant difference between the skin temperatures of the right and left great toe in a series of experiments.
3. To determine tolerance time of the felt boot and mukluk at minus 40°F.
4. To further establish the validity of paired observations in testing.
(Provisional Report, 8 October 1943)

It was concluded that there was no basic difference in the toe temperatures of the right and left foot and that small differences in the thermal insulation of various types of footgear could be determined. Certain advantages and limitations must be recognized in the utilization of this technique:

(1) The tolerance time is determined by the foot which becomes unbearably cold first. The other foot may or may not be unbearably cold and it is, therefore, impossible to collect tolerance-time data.

(2) Since right and left toe temperatures are compared in the same

exposure, morning and afternoon tests can be conducted without endangering validity of the statistical analysis of the data.

(3) The procedure is most desirable when testing two footgear items because each subject has two feet. By cross-mating all possible combinations, however, a study can be made of three or more footgear types and their relative effectiveness can be determined.

(4) Extraneous influences (diet, morale, variations in room temperature, etc.,) are minimized in this type of testing. All such factors operate on both feet to an equal degree.

(5) The wearing of the test combinations must be reversed on the feet for the second exposure in order to eliminate variables - difference in foot size causes undue constriction, slight differences in workmanship, or shape of test items, etc. A sample test can be planned as follows:

	<u>Right Foot</u>	<u>Left Foot</u>
Monday, AM	Felt Boot	Mukluk
Monday, PM	Mukluk	Felt Boot

This technique was also utilized in a test which necessitated the wearing of soiled socks. Such socks, for sanitary reasons, could be worn by only one man. An account of the results of this test is as follows:

In order to obtain an adequate comparison of the thermal insulation of the various types of sockgear at the end of a week's continuous wear it was necessary to evolve a new test procedure which would eliminate the necessity for a transfer of the soiled sockgear from one subject to another, since it was deemed inadvisable to rotate the used socks through all test subjects for hygienic reasons. It is believed that the test method evolved is a useful one and may be of considerable use in connection with testing of other items of footwear.

Briefly, the method depends on the comparison of the difference in temperatures of the two feet of each test subject at the end of their tolerance to cold; that is, at the time when a maximum difference was expected. In order to use this method, a different type of test item is worn on each foot. At least two observations are obtained for each test subject, with the test items worn on the alternate feet during the duplicate exposures, in order to eliminate possible variations between the two feet of the subject. In the present experiment, involving testing of sockgear, rotation of the gear from foot to foot eliminated the difference between boots as well as possible differences in the feet.

This method of testing was compared with the standard method of having the test item rotate between subjects during the comparison of the previously unused water-repellent and non-water-repellent sockgear. Both test methods agreed, and both showed no difference in thermal insulation of the two types of sockgear when new.

(Provisonal Report, 30-31 October 1944)

Trench foot casualties suffered during the Italian campaign in the Winter of 1943 were reflected in a series of vapor-barrier tests conducted in March 1944. The understanding of the test procedure is based, to some extent, upon an understanding of the possibilities of vapor-barrier sockgear; therefore, a short discussion is included with the description of test procedure:

Investigation of the use of vapor barriers as a means of preventing evaporative heat loss has been extended to include the use of impermeable socks in combination with standard sockgear. On the basis of theoretical considerations, it is evident that vaporproof socks would be of benefit in reducing cooling of the foot when the feet or sockgear were wet, but of practically no benefit when the feet and sockgear were dry. Since the feet perspire freely during vigorous exercise even in the cold, however, and since it is frequently necessary to remain inactive in the cold following a period of vigorous exercise, experiments have been conducted using a vapor barrier in conjunction with dry and damp socks.

The vaporproof socks were tested in conjunction with shoe-pacs worn with 1 pair of cushion sole socks and 2 pairs of ski socks in order to determine their effect

on the tolerance times, skin temperatures and moisture distribution of subjects sitting at rest in the cold with dry or damp cushion socks. The damp cushion socks were wet with 50 percent of their own weight of water. This amount of water was chosen because it has been found to be equivalent to the amount of water picked up by cushion socks following vigorous exercise of several hours duration in the cold.

Tolerance times, skin temperatures and moisture distribution were determined for subjects sitting at rest wearing damp cushion socks and dry ski socks without a vapor barrier, with a vapor barrier between the cushion sock and inner ski socks, and with a vapor barrier between the outer ski sock and the shoepac. In every case the cushion socks were wet with 50 percent of their own weight of water and the ski socks were dry at the start of the experiment. It is evident that the presence of a vapor barrier between the cushion sock and inner ski sock provided considerable protection, since tolerance times were significantly prolonged and skin temperatures at the end of one hour decidedly higher. When the vapor barrier was located between the outer ski sock and the shoepac, however, it failed to provide any additional protection.
(Provisional Report, 27 March 1944)

The benefit of an inner vapor barrier sock in addition to an outer barrier as a means of reducing the rate of evaporative cooling of the foot due to the presence of sweat in the sockgear was investigated in the Cold Room. In order to avoid the difficulties which arise during marches with vaporproof socks from breakage of same, and in order to give a constant baseline for day-to-day comparison of sockgear, an experiment was conducted in which eight soldiers put on one pair of damp cushion socks, two pairs of dry ski socks, an outer vapor barrier sock, and shoepacs on two successive days. Half of the soldiers wore an inner vapor barrier sock, between the cushion sock and ski socks on each of the two days. The cushion socks were wet with their own weight of water each day, approximately 90 grams. The men put on all sockgear at 1200 each day and engaged in routine activities until 1400, in order to allow two hours for the moisture contained in the sockgear to reach a distribution equilibrium between the skin and the nearest vapor barrier. After this two-hour period all men entered the Cold Room at an ambient temperature of plus 30°F., and remained at rest until unbearably cold. Tolerance times and skin temperatures were measured in the usual manner.
(Provisional Report, 7 August 1944)

Handgear

The importance of warm handgear as well as the difficulty of finding such protection was revealed early in the testing program. At that time, it appeared that some failures attributed to other test items were produced by inadequate hand protection. Questioning of the test subjects indicated the validity of this theory; therefore, investigations of handgear were emphasized.

Among the earliest recorded handgear tests was the following:

During the past two days four pairs of gray arctic gloves have been studied by four subjects. The exposure temperature has been +20°F., 0°F. and -40°F. Double arctic alpaca pile assembly was worn. During the first three exposures wristlets were not worn. In the fourth exposure at zero, wristlets were worn for comparison with a previous exposure without wristlets.

There were five measurements taken on each subject at one or more exposure temperatures. These were as follows:

1. Time to cool at rest without additional handgear.
2. Time to assemble 11 carriage bolts of assorted sizes. Average of two or three periods.
3. Length of time it was possible to carry 10-pound weights from one end of the cold chamber to the other (20 ft.).
4. Pages of book turned in two minutes. Averages of two or three periods.
5. Time for hands to cool when held against cold steel. (Provisional Report, 7 August 1943)

The many factors to be considered in handgear testing for thermal insulation were recognized. A manual-dexterity test was included because dexterity is one index of the thermal insulation.

As testing progressed through the Summer of 1943, it became clear that duration of exposure as well as repeated exposures were important factors in

determining the length of tolerance. Only a few exposures could be obtained during one day and great care was exercised to prevent serious frostbite. Moreover, long recovery periods were necessary to ensure valid data. These limitations were found to be present in excessively large degrees for handgear testing only.

In October 1943, the technique for cross-mating shoes on the feet was applied to handgear testing:

On 15 October the glove liner was tested by six subjects. The exposure temperature was 0°F. The object was to hold a steel bar in each hand in the vertical position until the hand became unbearably cold. In this manner the bar had to be gripped tightly and could not rest on any part of the hand, as is possible in the horizontal position. The bar was held until the hand became unbearably cold after which the bar was allowed to fall to the floor. The number of observations were doubled by using different handgear combinations for right and left hand. It is believed that with the type of experiment planned, the procedure of using right and left hand as different experiments is justified. Only two exposures were allowed each half day.

(Provisional Report, 16 October 1943)

At the conclusion of the series of tests on the glove liner, the fundamental principles and limitations of handgear testing were discussed in the Provisional Report for 22 October 1943:

The data from the ten experimental days on the glove liner are being assembled. As a result of these studies, certain standards for test procedures have evolved. Until these studies were underway, it had not been fully appreciated how small was the quantity of stored heat in the hands. Furthermore, the physiological characteristics of the hands are quite different from the feet and the difference in functional use between hands and feet is great. These two variations made the handgear study totally different from footgear. When the glove liner study was started, a variety of maneuvers was planned at each exposure for the hands. This schedule showed up certain defects that necessitated a revision of the procedures. It soon became apparent that the best method of obtaining comparable data at sub-zero temperatures

was to allow only one exposure per subject each 60 or 90 minutes. The remainder of the time was spent at much higher temperatures, plus 50° or plus 60°, restoring lost heat to the hands. If a long warming-up period is not allowed, the hands do not return to the same state as at the beginning of the first exposure. If comparable data are not desired, of course, such a warming-up period outside of the cold room is not necessary.

A second qualification is the need for only a few, possibly only one or two, procedures for the hands. The aim should be to have the subjects trained to perform one or two maneuvers that are sufficiently simple that training is not a factor. It is believed that more important than performing delicate operations, is the gross contact of the fingers with conductors of heat.

Two extremes may illustrate this, assembling carriage bolts and dismantling a Garand rifle. Once a subject knows how to take apart a Garand rifle, the time needed to do this at minus 40°F. is determined by the contact with the steel parts more than anything else. On the other hand, assembling carriage bolts, gives more uniform results in regard to contact with steel than does the assembly of a Garand rifle. Therefore, it seems best to make the procedure as simple as possible for reproducible results. Holding of steel bars is also a good procedure, since there is only one way to hold a heavy bar in the vertical position, and the surface area of the hands that comes in contact with the steel is similar from day to day and from subject to subject.

If firing a rifle were selected as a test procedure at subzero temperatures, there would be a great variation in each round fired. Except for an expert rifleman, the time to center on the target varies a great deal from round to round. Thus, on one day a subject might be able to fire 16 rounds with a good score before the fingers became unbearably cold, on another day the fingers might get unbearably cold in only 8 rounds with a similar score.

It is appreciated that assembling bolts or a similar procedure, is not duplicating field conditions. But it is believed that in this one instance, i.e., study of light-weight and medium weight handgear, that an attempt to duplicate field conditions will only lead to unsatisfactory results.

Finally, if one were to set up an experiment for the glove liner, the following is suggested:

1. Enter the Cold Room wearing the liner.
2. Sit at rest until the fingers or hands became unbearably cold. The hands to be held away from the body and not protected by it.
3. Walking on treadmill for warming-up.
4. Sitting at rest, assembling bolts or holding steel bars.
5. One exposure only each half day.

This procedure could be duplicated in the field during a field test with only a minimum of equipment.
(Provisional Report, 22 October 1943)

The next variation in technique was introduced on the receipt of a test directive requesting data relating to the effect of wind on tolerance time. The Cold Room was equipped with a fan creating wind velocities to 25 mph., and some method of protecting the body and face from the blast of cold air was required. This experiment was described as follows:

During the past two afternoons, experiments have been conducted to determine the effect of wind on tolerance time of soldiers wearing the wool glove insert with leather shell or the flannel glove with leather palm. The procedure consisted of sitting at rest next to the wind tunnel so that the body was not in the direct blast from the tunnel and holding the right hand into the air stream so that it was exposed to a wind velocity of approximately 12 mph. Seven soldiers participated. They were clothed in six-piece Arctic clothing in order to prevent premature generalized body chilling due to the slightly increased turbulence of the air in the Cold Room when the wind tunnel is in operation.
(Provisional Report, 10 February 1944)

Subsequently, protection was afforded by building a pillory through which only the hands were extended into the wind. The holes for the hands were placed in a stair-step manner so that each hand received the full effect of the wind.



TESTING IN THE COLD ROOM

Thermocouples on the fingers were used only in cases where very heavy handgear was being worn, never when very thin gloves were worn. The reasons for this were:

(1) It is not possible to measure skin temperatures accurately when the insulation covering the skin is as thin as the average glove liner. The gradient between skin and surrounding air is so steep that the temperature assumed by the thermocouple is excessively influenced by the cold air adjacent to it.

(2) The metal thermocouple itself induces heat loss from the finger and thereby influences tolerance times.

(3) The bulk of the thermocouple and the connecting wires impede the movement of the fingers in tests of manual dexterity.

Clothing Assemblies

Testing of separate items of clothing and clothing assemblies was initiated after the standardization of other types of testing. This type of testing also utilized the tolerance-time and toe-temperature technique. In testing a pile jacket, for example, toe temperatures were preferred to body temperatures because they were more responsive to losses in heat from the body. In testing any given item, therefore, the principle of overdressing other parts of the body was followed and the heat loss through the test item was reflected in the decrease in toe temperature as well as in the tolerance times.

Although skin temperatures other than toe temperatures were not normally determined, some tests required special measurements. An example follows:

Extra protection to the knees of soldiers seated at rest in the cold has been investigated in the Cold Room at 0°F., with a 3 mph. wind. The low wind velocity rather than a high velocity was chosen since it is assumed that at 0°F. soldiers in moving vehicles would be

provided some kind of windbreak either improvised on the vehicle or as an outer garment. Twelve soldiers sat at rest until unbearably cold on four successive days wearing the Zone 2 Uniform Assembly listed under Basic Items. On one of the test days the assembly was worn as listed, and on the remaining three days was modified in order to provide additional thermal protection to the knees. Three methods of protecting the knees were employed, as follows:

1. Wearing an extra pair of 50-50 underwear, over-size.
2. Wearing kneelets made from Socks, Wool, Arctic. The kneelets were approximately 15 inches long before they were put on.
3. Wearing wool trousers with a patch of double-faced wool pile inserted over the knee and lower thigh. The patch was elliptical shaped, 16 inches at the long axis and 11 inches at the short axis.

Tolerance times and great toe temperatures were recorded as usual, and in addition the temperatures of the skin over the knee was measured by means of thermocouples placed over the patella.

(Provisional Report, 20 July 1944)

Test procedures were only altered when requests for new or different types of information were received; then, old procedures were adjusted or new ones created to provide pertinent data. During the Summer of 1944, the problems of the moisture content of clothing and its effect on thermal insulation were extensively studied. The procedures used are described in the following excerpt:

The fact that clothing and sleeping gear are less adequate during damp cold weather than during dry cold at the same temperature is assumed empirically. It has been conjectured that this difference is due to the differential in moisture content between wool (or cotton) fabrics exposed to low or high relative humidity. The moisture content of the fabrics is known to vary with the relative humidity, rather than with the absolute water content of the surrounding atmosphere. The role of temperature in regulating the moisture content of cloth fibers is known to be a minor one in comparison to the influence of relative humidity.

Variations in the moisture content of wool sleeping bags and clothing have been obtained by preconditioning the gear for periods varying from 24 to 48 hours in atmospheres of high and low relative humidity. Humidification of clothing and sleeping bags was carried out in the Cold Room, at temperatures ranging from plus 20°F. to plus 40°F. Conditioning was carried out in the Cold Room because the relative humidity ranges from 90 to 95 percent in this location and equilibrium with a high moisture uptake is possible. The moisture regain of sleeping bags in the Cold Room was considerably greater than in a constant humidity-temperature room maintained at 65 percent relative humidity at 70°F. Dehumidification of the clothing and sleeping bags was carried out in a small room in which the temperature was maintained at 120° to 140°F., and the relative humidity at 10 to 15 percent. This room was not designed for this purpose, and so it was not possible to regulate the temperature more accurately. Heating of the room was obtained by blowing air over uncovered steam pipes with an electric fan. The absolute humidity in this room remained equal to that in the outdoor air, the drop in relative humidity was a result of the temperature rise in the room. Wool sleeping bags in the Cold Room came into moisture equilibrium with the atmosphere within 24 hours; those in the small hot room came into equilibrium in less time. All conditioning was for a period of at least 24 hours, frequently for 48 hours. The mean weights of the same wool sleeping bags in the laboratory, in the Cold Room and in the small hot room were as follows:

Exposure To	Weight grams
120° - 140°F., 10-15 percent Relative Humidity.....	1560
80° - 90°F., 40-50 percent Relative Humidity.....	1653
30° - 40°F., 90-95 percent Relative Humidity.....	1744

.....The effect of preconditioning on the thermal insulation of clothing and wool sleeping bags was determined by measuring tolerance times and skin temperatures for eight soldiers sleeping in clothing and sleeping bags previously conditioned to high and low relative humidities by the methods outlined above.

(Provisional Report, 15 August 1944)

Following construction of the All-Weather Chamber and other rainmaking facilities, another type of testing was instituted. This required exposure to rainfall followed by a standard thermal-insulation test. Two examples of this type of testing are described as follows:

The present series of experiments were conducted in the All-Weather Chamber at an exposure temperature of plus 50°F. in the presence of a 15 mph. wind. Nine soldiers entered the room and remained there for five hours, irrespective of their tolerance time at rest. A 15 mph. wind was maintained in the room throughout this period. During the first 30 minutes in the chamber all men were exposed to a driving rain of 4 inches per hour. The men walked about during this period. At the end of the exposure to rain the subjects sat at rest until unbearably cold or until the end of the exposure period. Tolerance times were measured from the time they stopped walking in the rain. Each soldier was exposed on three successive days. A different uniform assembly was worn each day. The mittens were not worn during the exposure to rain, but were put on after the rain was stopped. After becoming unbearably cold the participants were permitted to warm up by marching on the treadmill. The relative fit, comfort and utility of the gear was considered during this period, as well as during the exposure to rain and wind. Certain articles of clothing were weighed prior to the start of the test and again at the end of the five-hour test period.
(Provisional Report, 13-14 September 1944)

The study of the thermal insulation provided by untreated and treated trousers after exposure to rain was conducted in the Cold Room at temperatures of plus 20°F. and plus 30°F. Under both conditions no significant difference in thermal protection was detected. The experiment involved one half hour in the Rain Chamber where twelve test subjects were exposed to one inch per hour rain. Four cycles of crawling and rubbing the trousers during this period tended to increase the moisture gain of the trousers and drawers. Before entering the Cold Room the test subjects changed into dry clothing with the exception of the wet trousers and drawers. For the initial test on thermal insulation the ambient temperature of plus 20°F. proved to be unduly cold and a satisfactory series of skin temperatures were not obtained. At plus 30°F., however, all test subjects remained in the Cold Room for at least forty minutes and the resultant data were extended so as to permit a detailed analysis.
(Provisional Report, 8-10 April 1945)

Another variation included exercise as an inherent part of the test:

Eight soldiers spent eight days in the Cold Room at plus 20°F. evaluating the thermal insulation provided by the standard and test items. The participants wore each test suit and the standard outfit on two consecutive days. On the first day of each two-day period, the men entered the Cold Room and remained at rest until unbearably cold. The Parka hoods were kept buttoned at all times and the trouser cuffs were tucked into the shoe-pacs. Thermocouples were used to measure toe temperatures and the tolerance times of each man were obtained. On alternate days, which represent a second phase, the men entered the Cold Room clothed as on the previous day but performed strenuous exercise immediately upon entering. The exercise performed was the same for each man and was constant throughout the test. It consisted in stepping from the floor onto a platform 16 inches high and back down to the floor again with both feet. A cadence of one step (1/4 cycle) per every 1/2 second was continued for three minutes. This exercise was sufficiently strenuous to cause most men to sweat freely. Following exercise, the men remained at rest until unbearably cold. Toe temperatures and tolerance times were recorded during the time of inactivity.
(Provisional Report, 24-25 September 1945)

After V-E Day, a critical shortage of trained test subjects reduced the probability of obtaining accurate tolerance times and toe temperatures. The success of a test program is based upon the intelligent and full cooperation of the test subjects and this necessarily includes a desire to remain in the Cold Room until "unbearably cold." Since this objective had become difficult to attain (for reasons which included a general feeling of lethargy and apathy on the part of the personnel), a technique designed to forestall the undesirable effects of the situation was instituted. In this procedure, all test subjects were required to remain in the Cold Room until their toe temperatures had declined to a specified point. This was selected by analyzing data from previous tests and determining the average temperature at which most subjects left the Cold Room. This point was increased sufficiently to provide for those subjects who were more susceptible than others

and who, therefore, became unbearably cold more quickly. The temperature assigned in most cases was plus 58°F. Although some success was attained with this procedure, it was a poor substitute for the standardized tolerance test when intelligent, willing, and cooperative subjects participate.

Headgear

Testing of headgear comprised a small part of the testing program, but it was, in some instances, the most difficult. Skin temperatures were difficult to determine and often lacked significance. Moreover, during tests in wind, different results were collected when the direction of the wind was altered. These problems were not completely solved but the test technique continued to improve. An example of the difficulties presented in headgear testing appears in the following excerpt from the Provisional Reports:

The protection afforded soldiers sitting at rest in the cold room in a 3 mph. wind and in a 20 mph. wind has been studied while wearing the experimental hood for comparison with the cap, field, cotton with ear flaps down and jacket collar turned up. The remainder of the clothing was kept constant.....The mean tolerance time for men wearing the hood is one-third longer than for men wearing the cap with flaps turned up. The internal variation in these data is sufficient, however, to rob them of statistical significance. Nevertheless, it is the opinion of the laboratory that the difference in mean tolerance time represents a real difference in the warmth of the gear. Toe temperatures following 25 minutes of exposure show the same trend as the tolerance times and suggest that body cooling was more rapid when the cap was worn than when the hood was worn.
(Provisional Report, 21 April 1944)

In addition to hood testing, face masks were also investigated. The procedure required an exposure in the Cold Room while facing a wind of 20 to 25 mph. Tolerance times were easily obtained but often were affected by the fit of the face mask; only a slight opening caused by poor fitting introduced cold air sufficient to produce unbearable skin temperatures. The variations produced by poor fitting obscured the variations caused by differences in material and thereby produced great difficulties. Only by diligent and careful personal supervision of the testing could these difficulties be reduced.

CHAPTER III

PHYSICAL METHODS FOR THE DETERMINATION OF THERMAL INSULATION

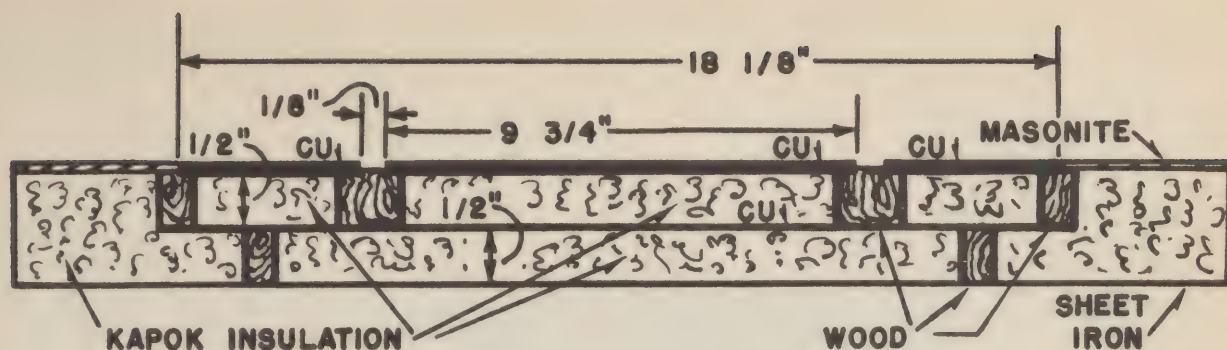
Shortly after the activation of this laboratory it was realized that specially designed apparatus would be required for the measurement of the thermal transmission of textiles. The proper types were chosen to meet the particular needs and diversity of fabric materials encountered in Quartermaster items. The design principle used by Cleveland¹ was adopted; other types were constructed at a later date but all were based on the same operating principles as this first guard ring flat plate. The flat plates are utilized for measuring the thermal insulation value of sleeping bags, sleeping-bag pads, pile fabrics, and other insulating materials. Thin fabrics and clothing assemblies are best tested on a guarded cylinder-type apparatus.

These thermal transmission instruments have been in use at this laboratory for the past two years and comprise an important part of its testing equipment. The guarded cylinder was developed from the early unguarded type which was part of a mannikin constructed by representatives of the National Bureau of Standards. Early unguarded models caused errors as large as 20 percent owing to nonradial heat losses (end losses). Present types now in use eliminate this error and produce results which are both consistent and in good agreement with flat-plate measurements. Sockgear and footgear, however, require a special type of apparatus. Therefore, an electrically heated bronze foot was developed to test a wide variety of sockgear and footgear assemblies. By means of the guard ring flat plate, the guard ring cylinder, and the bronze foot, testing of a large percentage of Quartermaster clothing items has been conducted.

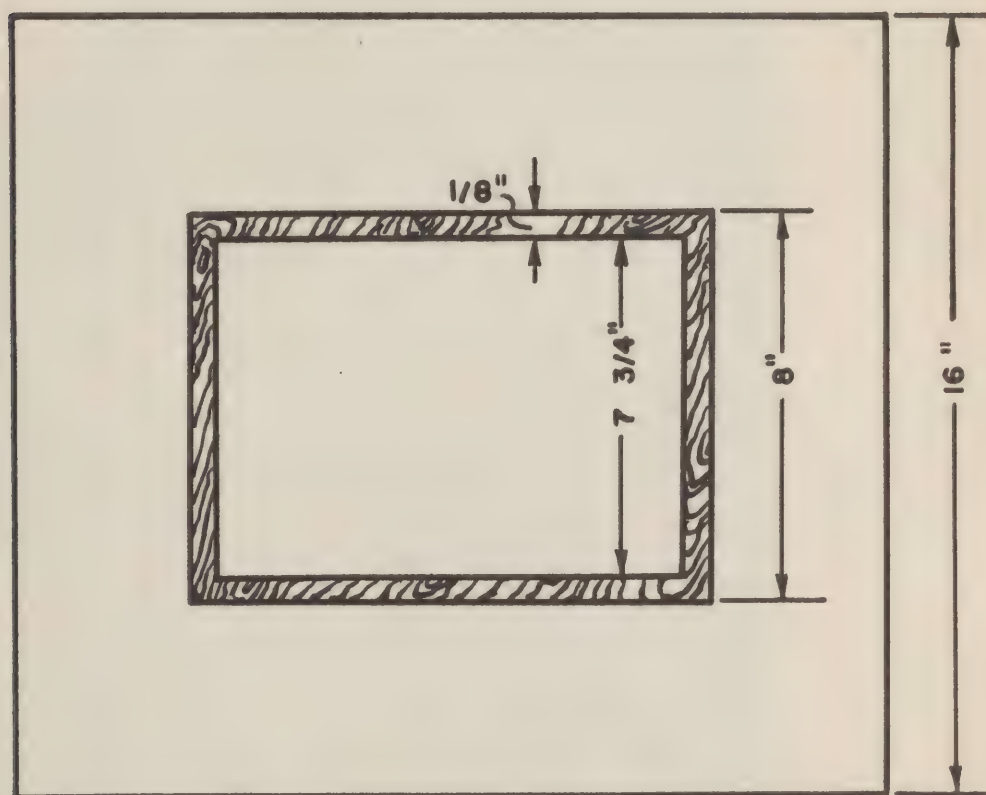
¹Richard S. Cleveland, "An Improved Apparatus for Measuring the Thermal Transmission of Textiles" (National Bureau of Standards - Journal of Research 1937) Vol. 19, p. 675.

Guard Ring Flat Plate No. 1

Guard Ring Flat Plate No. 1 is shown in Figures I, II, and III. It was constructed from No. 22 gauge copper and has three sections: (a) the central test section, (b) the guard ring, and (c) the bottom guard plate. Each section is separately heated by constantan resistance wire heaters. Copper-constantan thermocouples were soldered to each section for temperature-measurement purposes. A piece of 18-oz. wool serge fabric covered the entire surface of the apparatus; over this layer of fabric was a sheet of standard cork insulation supplied by the Bureau of Standards. (The thickness and insulation value of the cork had been previously determined by this agency.) Thermocouples were applied to both surfaces of the cork insulation. The fabric to be tested was placed on top of the cork and temperature gradients across both the cork and the material under test were measured. The thermal insulation value of the test material was calculated from a knowledge of these temperature gradients and the power input to the test section. Separate variacs for controlling the voltage input to the central test section, guard ring, and bottom guard plate were used. The original temperature control circuit (Figure III) was subsequently discontinued since it was found that the Micromax lacked sufficient sensitivity and speed of response. This original circuit employed a Micromax, with modifications for temperature recording, thermostating, and synchronous switching. Even though it proved unsatisfactory, it was the beginning of research on electrical temperature-control circuits which resulted in the development of the Thermistor Electronic Thermoregulator.



A.



B.

- A. VERTICAL CROSS SECTION THROUGH GUARDED FLAT PLATE TEXTILE INSULATION APPARATUS.
- B. TOP VIEW OF GUARDED FLAT PLATE TEXTILE INSULATION APPARATUS.

FIGURE I



FIGURE IIA

GUARDED FLAT PLATE SHOWING SERGE LAYER AND CORK STANDARD
WITH ATTACHED THERMOCOUPLES ABOVE

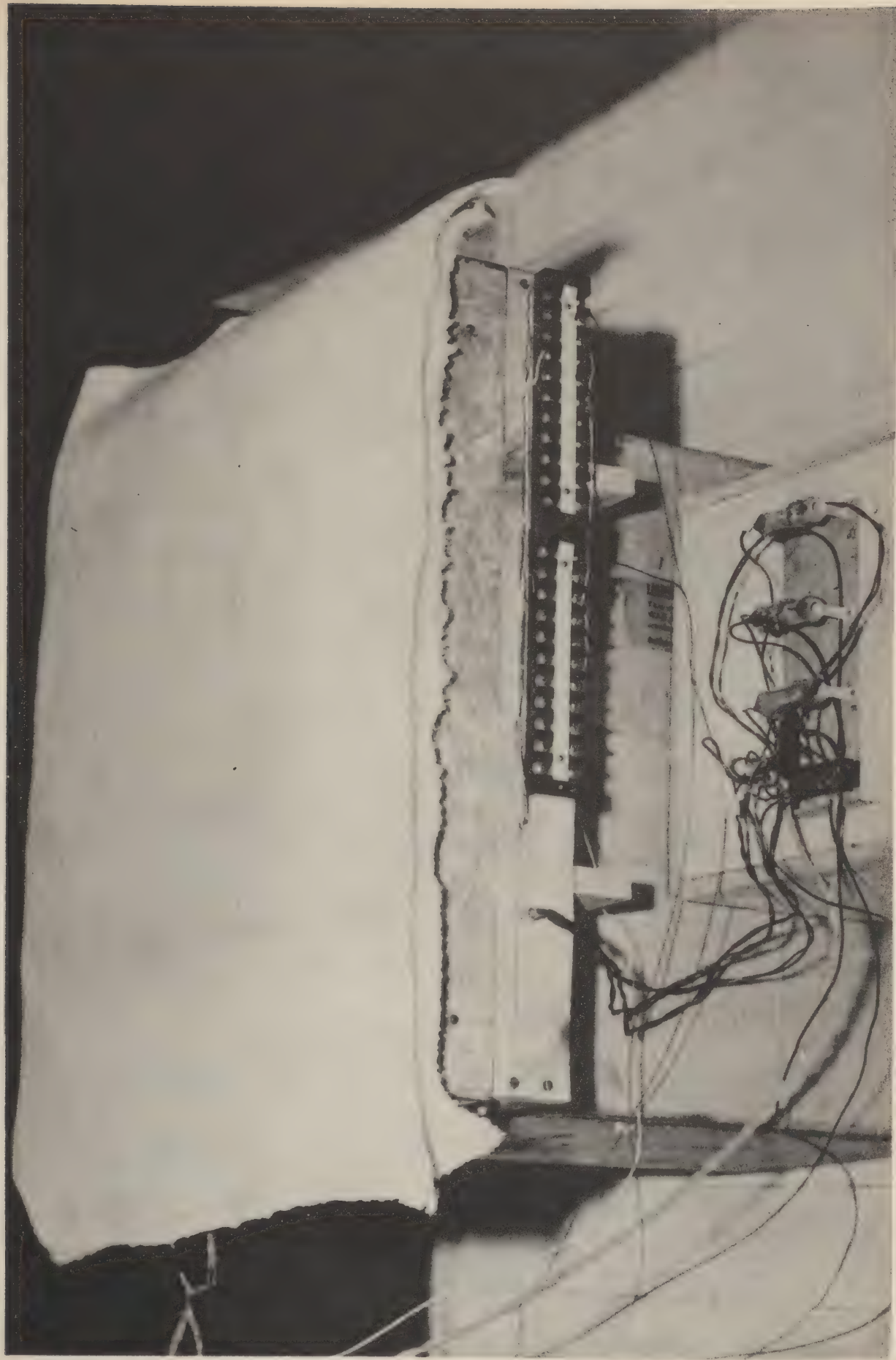
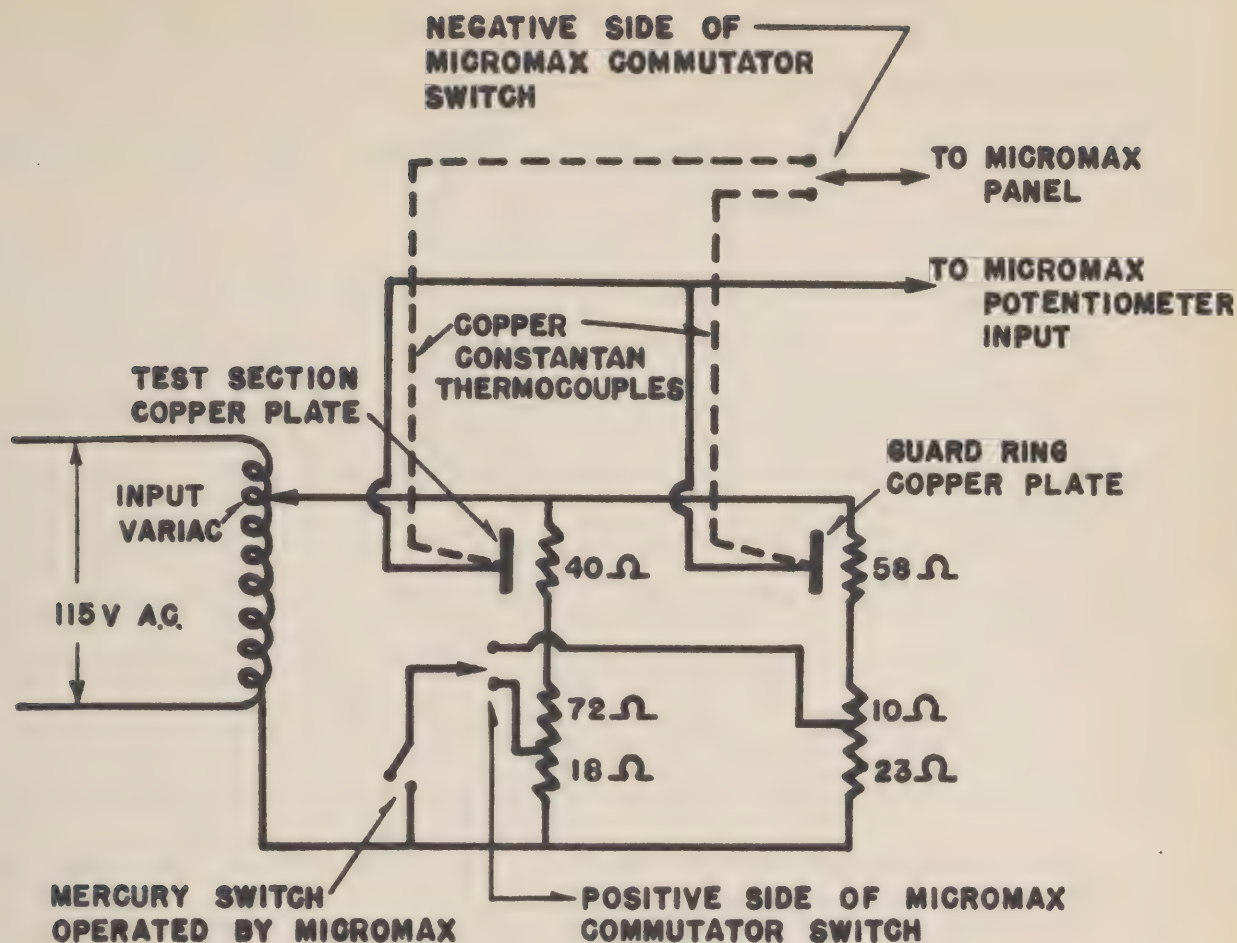
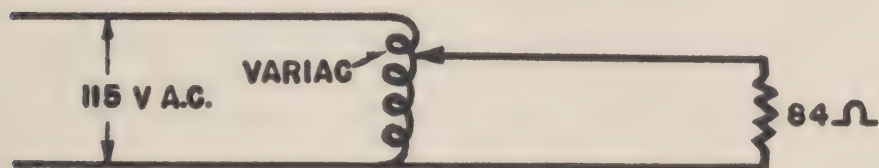


FIGURE II B

GUARDED FLAT PLATE WITH TWO LAYERS OF DOUBLE WOOL PILE OVER THE CORK STANDARD



A.



B.

ELECTRICAL CIRCUIT OF GUARDED FLAT PLATE

A. TEST SECTION AND GUARD RING CIRCUIT

B. BOTTOM GUARD PLATE CIRCUIT

FIGURE III

The copper plates for the test section, guard ring, and bottom were cut to size. B & S No. 30 constantan wire was used for the heating elements on all three plates with resistances as follows:

(1) Test Section - 68 ohms

(2) Guard Ring - 60 ohms

(3) Bottom Plate - 85 ohms

Two coats of insulating varnish, capable of withstanding continuous heating at plus 150-160°F., were applied to the test, guard, and bottom plates. The constantan heating wire was bonded to the plates, in the form of a grid, with Duco cement. The test section and guard-ring plates, with heating elements completed, were attached to the wooden frame by means of small flat-headed screws, countersunk to produce a level surface. The leads from the test section and guard ring were brought out through one side of the wooden frame. The frame was then inverted and the space between the top and bottom plate was filled with kapok. The bottom plate was put into position, fastened securely, and leads brought out through the side. Wires were tagged to facilitate proper hookup on the terminal strips. The masonite was then set in position and the sheet iron screwed to the wooden spacers prior to attachment to the wooden frame. Insulation was accomplished by using "spaghetti" and an insulating varnish.

The copper-constantan thermocouples were made from B & S No. 36 wire and were soldered to the test, guard ring, and bottom plates. Lead wires from the thermojunctions were carried across the plates and held in place with Scotch Tape. Two Jones' terminal-strips were mounted on the side of the sheet iron; one small strip was used for the power connections for the heating elements and a larger one provided connections for the copper-constantan

thermocouple leads. Insulation resistance between plates was in excess of 5,000,000 ohms. As a final step, the surface of the apparatus was covered with two coats of flat black paint to simulate the emissivity of the human skin.

The standard cork obtained from the Bureau of Standards had the following properties:

- (1) Density = 10.06 lbs./ft.³
- (2) Thickness = 1.56 cm
- (3) Clo Value (insulation) = 2.2 clo units

The clo value was obtained from the following formula:

$$K_t = K_{90^\circ\text{F.}} [1 + a (t - 90)]$$

K_t = thermal conductivity in BTU/min., ft.²/°F./inch
at a mean temperature of $t^\circ\text{F.}$

$$K_{90^\circ\text{F.}} = 0.302$$

$$a = 0.0012$$

$$t = \text{mean temperature of Cork in } ^\circ\text{F.}$$

When properly adjusted and operated, Guard Ring Flat Plate No. 1 produced results which were reproducible to a consistency of less than 3 percent. All measurements were made in a constant temperature room.

Guard Ring Flat Plate No. 2

As the study of thermal insulation was extended, it was necessary to construct a second guard ring flat plate apparatus to handle the volume of test work. The method of operating Guard Ring Flat Plate No. 2 is similar to Flat Plate No. 1 (Figure IV). The test section, guard ring, and bottom plates were constructed from No. 22 gauge copper. Each section was separately heated by B & S No. 30 constantan resistance wire heaters, bonded to the



FIGURE IV A
GUARDED FLAT PLATE
UNCOVERED SHOWING CORK STANDARD



FIGURE IV B

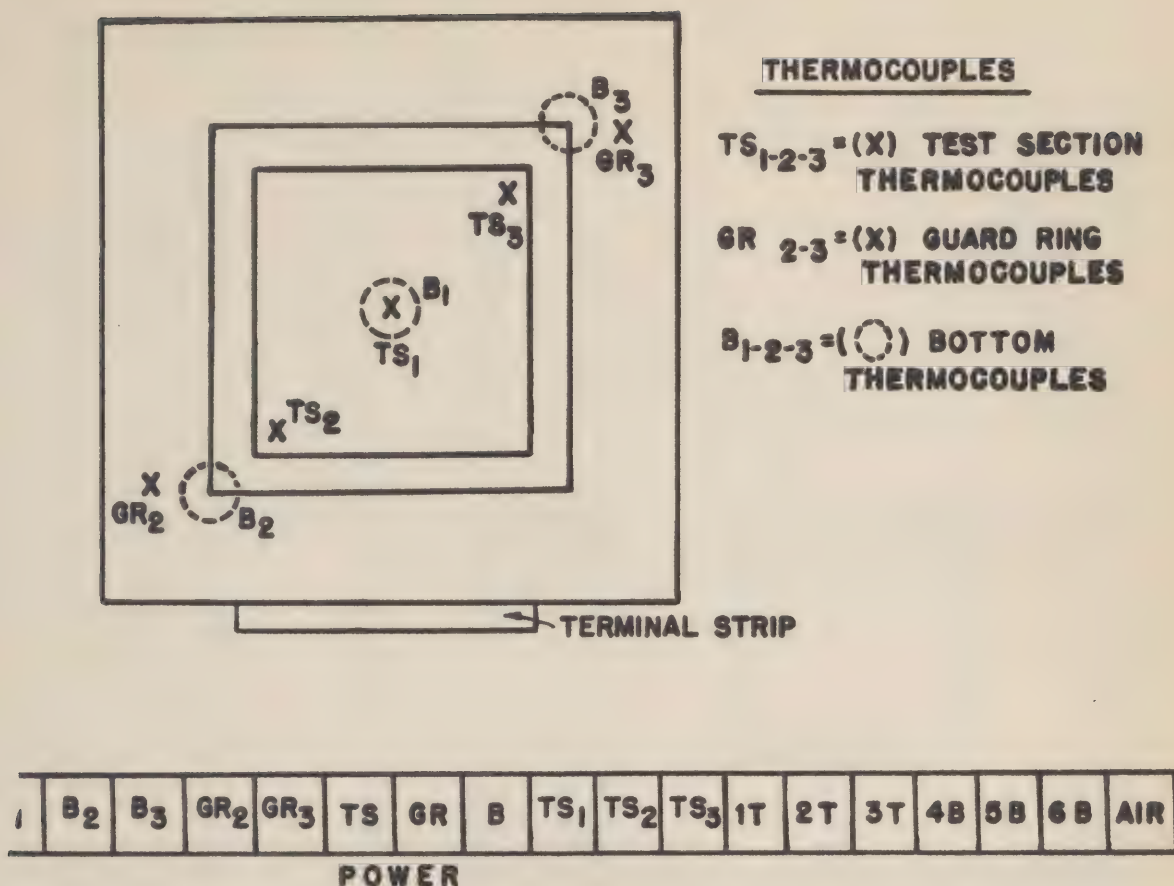
GUARDED FLAT PLATE WITH SECTION OF BAG,
SLEEPING, MOUNTAIN IN PLACE

copper plates. Copper-constantan thermocouples (Figure V) were soldered to the plates for temperature-measurement purposes. Standardized composition cork was used in some instances; at intervals, the cork was removed and the thermal insulation value was determined directly by the heat input method. Separate variacs controlled the electrical input to the test section, guard ring, and bottom plates. During a test, the variacs were manually operated to bring all three plates to the same temperature.

The over-all dimensions and component sizes of this apparatus are shown in Figure VI. Flat Plate No. 2 is essentially the same as No. 1 except for a few changes in construction. The copper plates were cut to size and cleaned. B & S No. 30 constantan wire was used for the heating elements of the test section, guard ring, and bottom plates with resistance as follows:

- (a) Test Section = 80 ohms
- (b) Guard Ring = 176 ohms
- (c) Bottom Plate = 215 ohms

An external resistance of 160 ohms was placed in series with the test section to facilitate voltage measurements. The heater wire was bonded to the plates, in the form of a grid, with Duce cement. In order to decrease thermal lag, no kapok filler was used between plates in this apparatus. The plates were attached to the wooden frame as shown in Figure VI and the outer wooden framework was grooved to permit flush-mounting of the guard ring and bottom plates. Each side of the outer framework comprised a separate piece, held together by glue and reinforced with corrugated metal strips. The wooden spacers were also grooved and provided a 1/8-inch wooden insulation barrier between the test section and guard ring plates. Plywood was used for the bottom instead of sheet iron as in Flat Plate No. 1.



TERMINAL STRIP ON FLAT PLATE — FRONT VIEW

STANDARD CORK WIRING

1T, 2T, 3T, = TOP THERMOCOUPLES
 4B, 5B, 6B, = BOTTOM THERMOCOUPLES

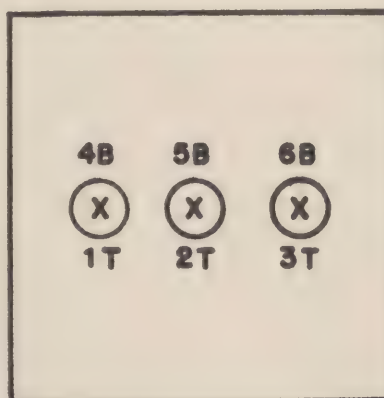
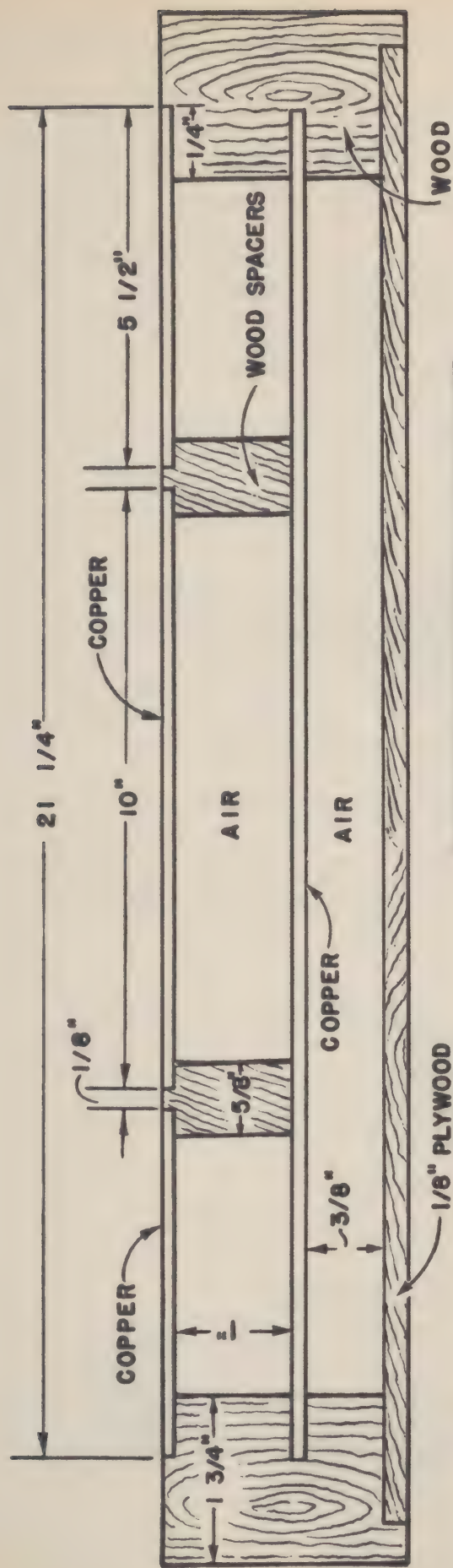


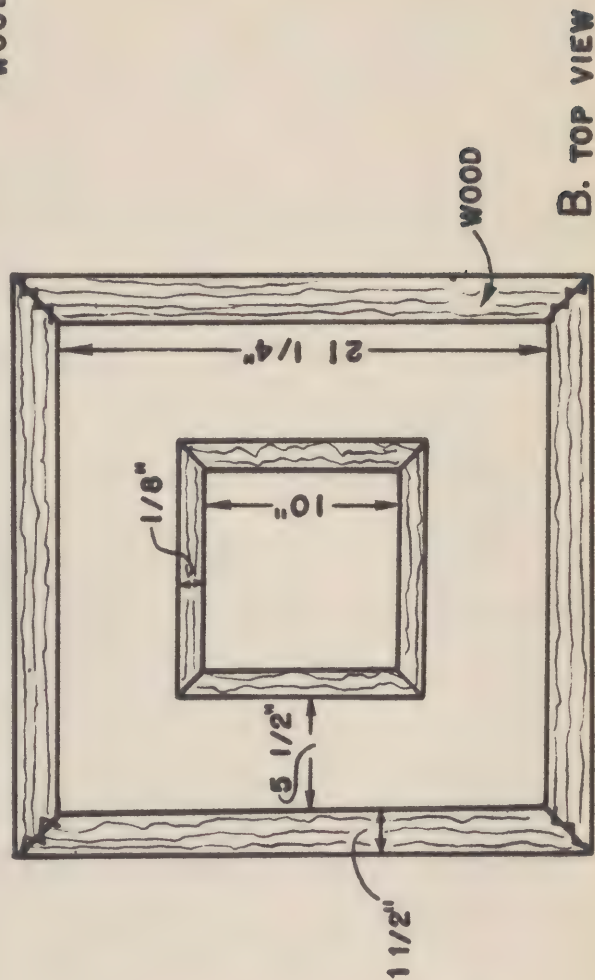
FIGURE V

GUARD RING FLAT PLATE NO. 2

LOCATION OF THERMOCOUPLE AND POWER LEADS ON
 TERMINAL STRIP



A. VERTICAL CROSS SECTION



B. TOP VIEW

FIGURE VI

GUARD RING FLAT PLATE NO. 2

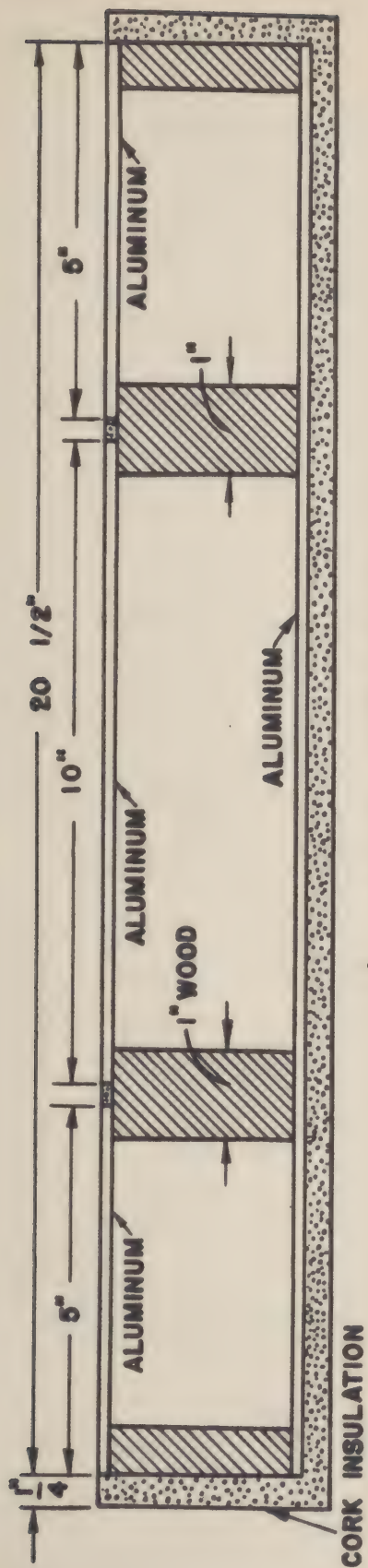
B & S No. 36 copper-constantan thermocouples were soldered to the plates and leads were brought out through one side to a terminal strip. Thermocouple locations were as indicated in Figure V. Insulation resistance between plates was tested when final assembly had been completed and was determined to be in excess of 5,000,000 ohms.

The two flat plates described above were mounted on small tables in a constant temperature room. The heat source was always at the bottom of the fabric under test. It was thought that a flat-plate apparatus must be capable of providing a downward as well as an upward flow of heat through any test material. This would be the case when a soldier is lying on a sleeping-bag pad and would especially apply to unfilled, inflatable pads. To meet this requirement, Guard Ring Flat Plate No. 3 was constructed. An important feature of this new apparatus was the elimination of manual control of electrical input by use of Thermistors mounted on each plate. These Thermistors, in conjunction with the Thermistor Electronic Thermoregulator, provided automatic temperature control. Guard Ring Flat Plate No. 3 possessed several advantages over the first two models constructed at this laboratory. They included:

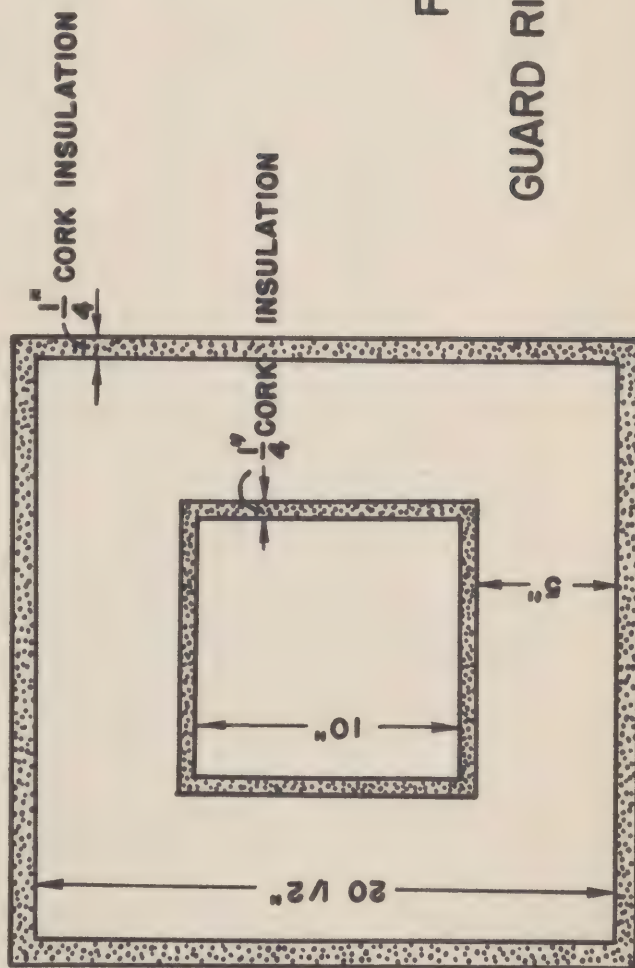
- (1) Lightweight construction
- (2) Greater portability
- (3) Ease of operation
- (4) Electric temperature control to 0.1°F.
- (5) Directional control of heat flow

Guard Ring Flat Plate No. 3

Guard Ring Flat Plate No. 3 was similar in size and shape to No. 2. The section plates were constructed from No. 22 gauge aluminum and cut to size as shown in Figure VII (A) and (B). The wooden frame (Figure VII (C)



A. VERTICAL CROSS SECTION



B. TOP VIEW

FIGURE VII

GUARD RING FLAT PLATE NO. 3

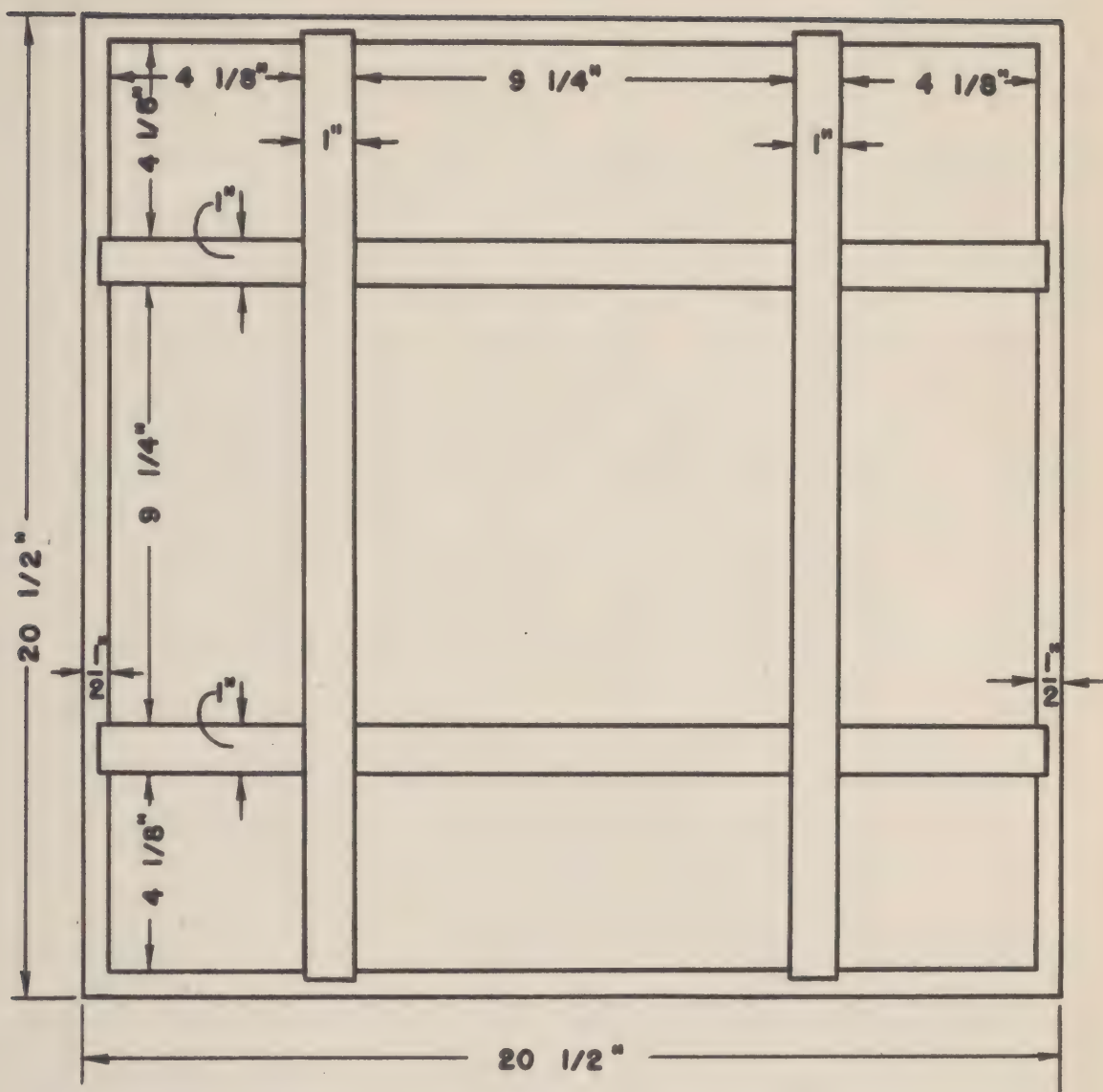


FIGURE VII C

WOODEN FRAME FOR GUARD RING FLAT PLATE NO. 3

was constructed from clear, hard maple. The unit pieces of the frame were glued and reinforced with screws to give a strong, even surface for plate mounting. The plates were cut to size and grooved to sufficient depth with a Motor Tool to allow for embedding the Thermistors and thermocouples.

A V-592 Thermistor with a resistance of 810 ohms at plus 75°F. was used for the test section. The Thermistor was insulated from the aluminum plate by coating the groove with Fleck's perfected cement. The Thermistor leads were left bare for 2 inches and B & S No. 30 copper wire (single cotton braid insulation) was used for extension leads. It is essential that the cement be completely dry before testing for insulation resistance; 10 to 15 hours is usually sufficient. The cement is quick setting, however, and must be applied rapidly. An amalgam of silver and mercury was used to fill and level off the groove after the Thermistors and extension leads had been mounted. The Thermistors are located as shown in Figures VIII A,B and had electrical resistances as follows:

- (1) Test-section plate = 810 ohms at plus 75°F., type V592
- (2) Guard-ring plate = 750 ohms at plus 75°F., type V592
- (3) Bottom plate = 750 ohms at plus 75°F., type V592

The thermocouples were made from B & S No. 30 copper and constantan wire (Leeds Northrup 1938 calibration). The thermojunctions were dip-soldered and flush-mounted in grooves in the same manner as employed for Thermistors. Thermocouples were located on the plates as shown in Figures VIII A and B. Heating elements for all plates were constructed from B & S No. 30 constantan wire with a resistance of 3.3 ohms/ft. The manner of applying the heating element to the plates was altered slightly from former procedures. A piece of white cotton duck fabric was cut to fit each plate size. The heater wire was laid out on the cloth in the form of a grid and fastened temporarily with Scotch Tape. The wire was then sewn to the cloth by machine

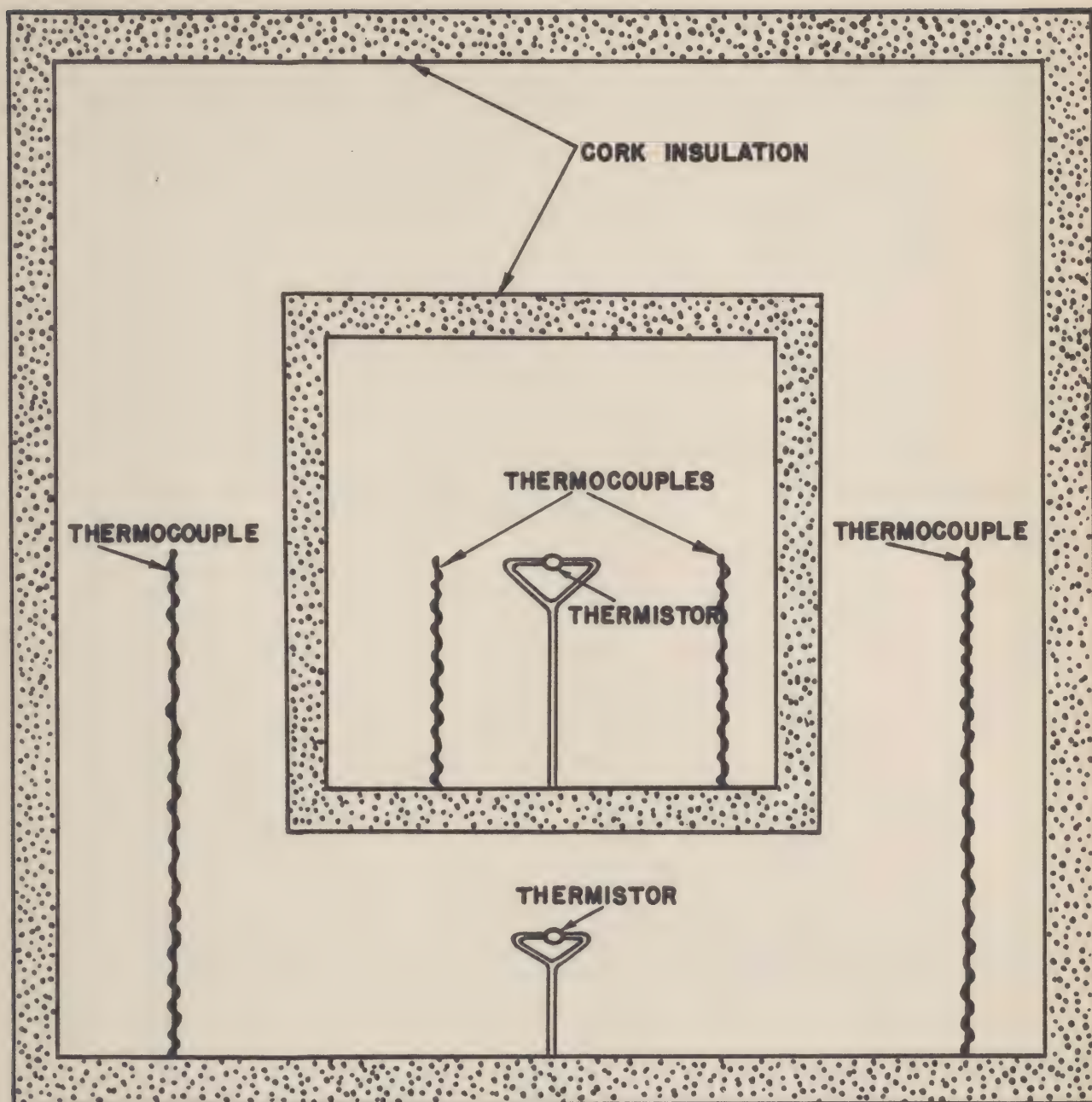


FIGURE VIII A

GUARD RING FLAT PLATE NO.3

LOCATION OF THERMISTORS AND THERMOCOUPLES ON TEST SECTION
AND GUARD RING

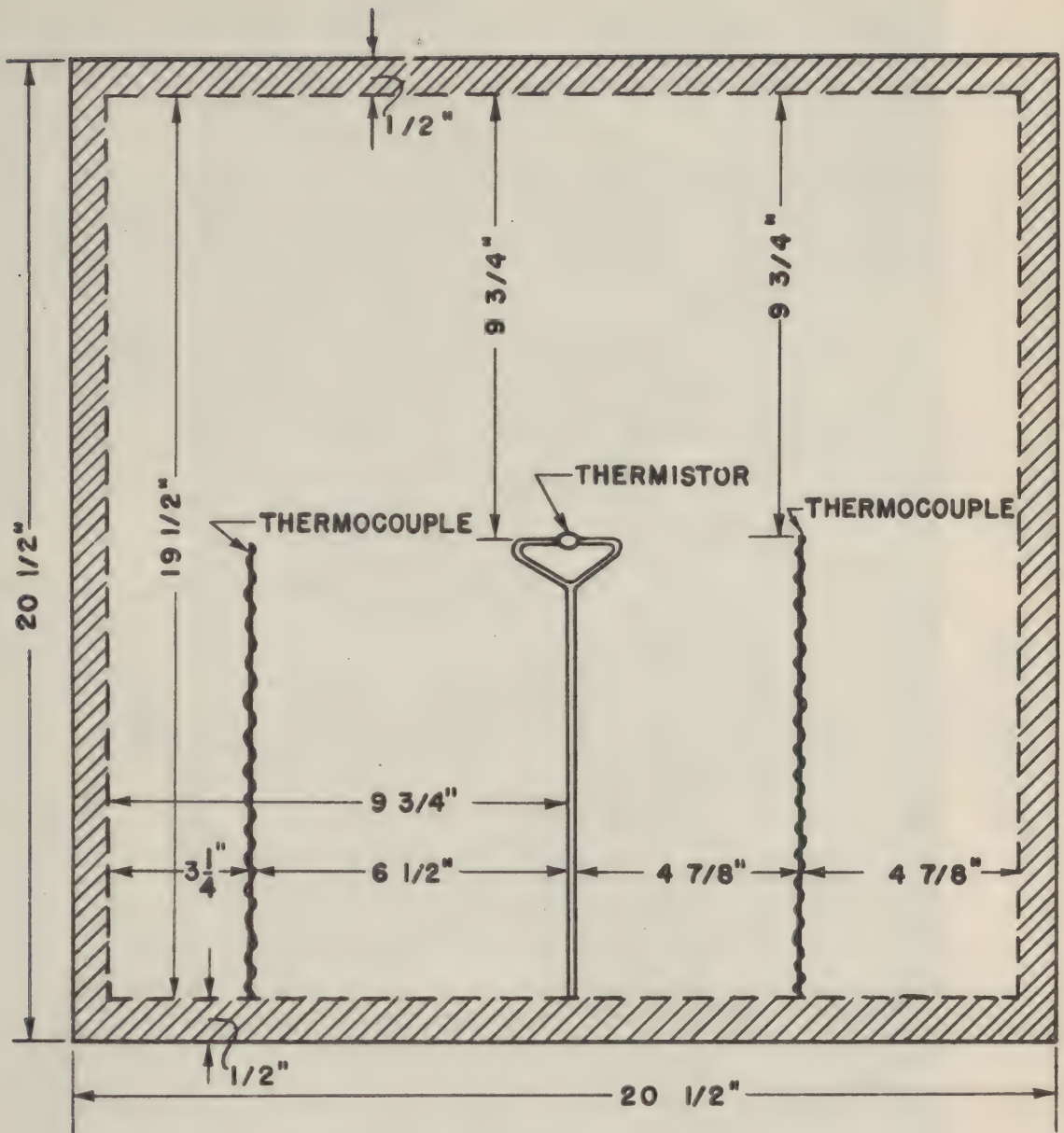


FIGURE VIII B

GUARD RING FLAT PLATE NO. 3

LOCATION OF THERMISTORS AND THERMOCOUPLES ON BOTTOM PLATE



FIGURE IX

GUARD RING FLAT PLATE NO. 3. SECTION OF BAG, SLEEPING, MOUNTAIN UNDER TEST.

and thereby held securely in position. The cloth with heating wire attached was bonded to the plate with Pliobond, a synthetic adhesive cement. Prior coating of all plates with at least two applications of insulating varnish gave high insulation resistance. Twenty-four hours of air-drying were necessary to allow complete setting of the bonding agent. The plates were mounted on the wooden frame and held securely with screws, countersunk to permit a level surface. All lead wires were brought out through one side of the wooden frame and connected to two Jones' terminal-strips mounted on the frame. The electrical resistances of the heating elements were as follows:

- (1) Test-section plate = 90 ohms
- (2) Guard-ring plate = 220 ohms
- (3) Bottom plate = 285 ohms

An external resistance of 225 ohms was put in series with the test-section element. As a final step in completing the Guard Ring Flat Plate No. 3, a layer of composition cork sheeting 1/4 inch in thickness was bonded to the sides and bottom of the apparatus to prevent excessive heat losses. The top of the apparatus was then covered with two coats of flat black paint.

METHOD OF CALCULATION FOR FLAT PLATES

For the purpose of illustrating the test method employed in the utilization of a flat plate apparatus, a typical calculation of clo value is presented:

$$\text{General Formula: } \underline{\text{Clo}} = \frac{\Delta T}{\frac{.324 \times \text{Watts} \times 0.86}{M^2}}$$

Where $-\Delta T$ = Temperature gradient across test material ($^{\circ}\text{F.}$)

.324 = Conversion factor to clo units

.86 = Kilogram calories in 1 Watt hour

M^2 = Surface Area of test section in square meters

Calculation of M^2 : 10" x 10" (Flat Plate #2) = 100 sq. in. = 6.45×10^2

$$\text{Clo} = \frac{\Delta T}{(.324 \times .86) \times \text{Watts}} = \frac{\Delta T}{4.32 \times \text{Watts}}$$

$$(6.45 \times 10^2)$$

or $\text{Clo} = \frac{.2314 \times \Delta T}{\text{Watts}}$ (specific formula)

Calculation of Watts: $\text{Watts} = \frac{E^2}{R}$

E^2 = Input Voltage to test section, squared

R = Resistance of test section in ohms

Example from data collected on Flat Plate No. 2:

Test Section Resistance = 79.59 ohms

External Resistance in series with test section = 161.2 ohms

total resistance = 240.79 ohms

Total Voltage = 38.2 volts

$$\text{Voltage to test section} = \frac{38.2}{1} \times \frac{79.59}{240.79} = \underline{12.63 \text{ volts}}$$

$$\text{Watts} = \frac{E^2}{R} = \frac{12.63^2}{79.59} = \underline{2.005 \text{ watts}}$$

ΔT across Pad = 32.5°F.

Applied to specific formula:

$$\text{Clo} = \frac{.2314 \times \Delta T}{\text{Watts}} = \frac{.2314 \times 32.5}{2.0} = \underline{3.76 \text{ clo}}$$

Intrinsic Clo of Pad = 3.76 - 0.67 = 3.09 Clo.

(Where 0.67 clo = insulation of Ambient Air)

Guard Ring Brass Cylinder

A guarded brass cylinder has been used extensively for testing thin fabrics and fabric assemblies. This guard ring brass cylinder (Figure X) was built in 3 sections separated by 1/8-inch wooden spacers. The test section was 8 inches long and each guard ring section 4 inches. Seamless brass

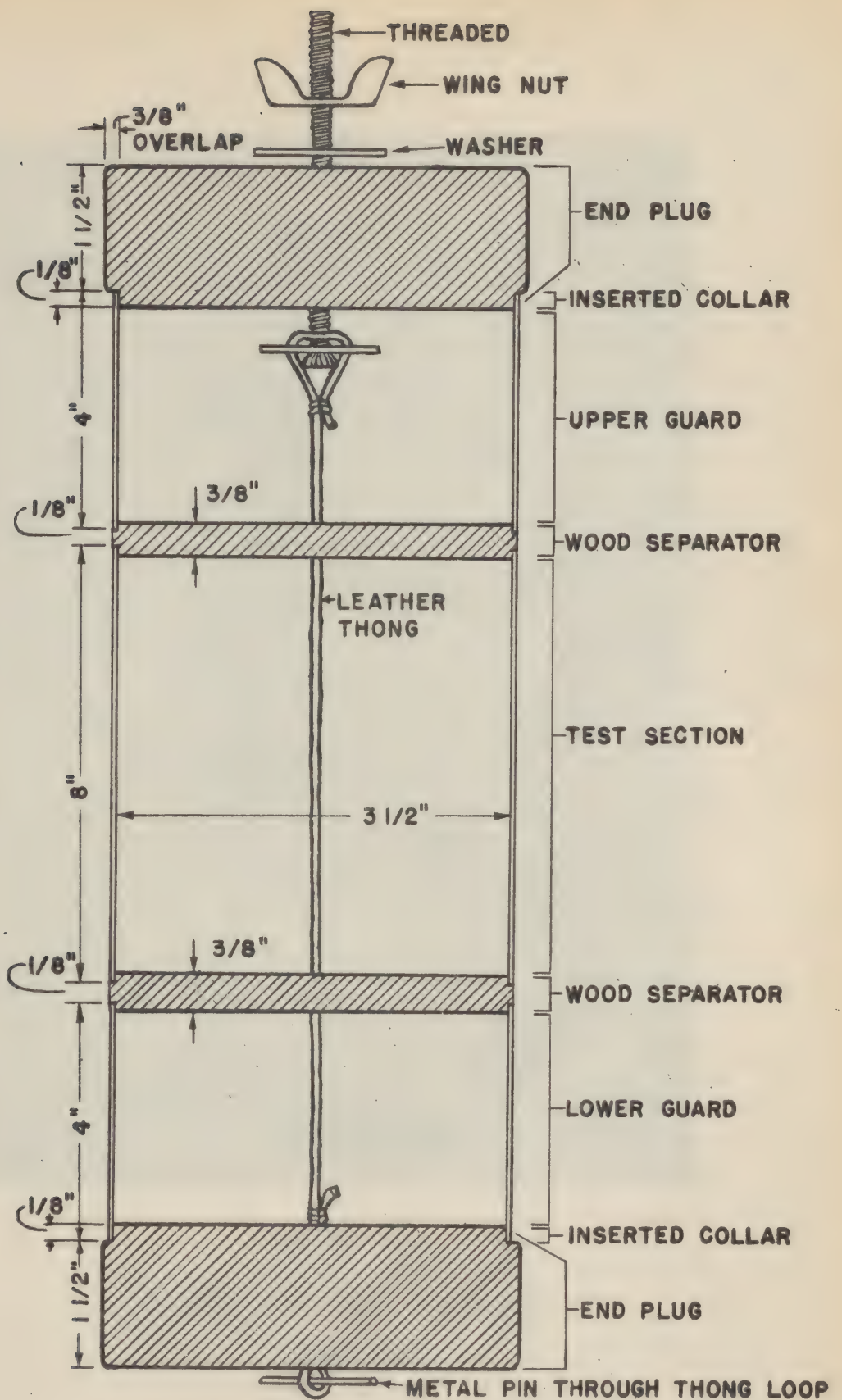


FIGURE X
 GUARD RING BRASS CYLINDER



FIGURE **XI**

GUARDED BRASS CYLINDER

tubing with a wall thickness of .045 inch and an inside diameter of 3.5 inches was used for all sections. The end plugs and wooden spacers were made from hard maple.

The sections were cut to size from the brass tubing. The end plugs were cut from 4"x4"x1 $\frac{1}{2}$ " hard maple stock and turned on a lathe to match the cylinder diameter. In a like manner, the wooden separators were cut and shaped to proper fit. The heating elements were made from B & S No. 30 constantan wire (cotton covered) with a resistance of 3.3 ohms/ft. The wire was wound on pieces of cardboard previously measured to match the inside circumference of the cylindrical plates. Slits were cut along the top and bottom edges of the cardboard every 1/4 inch to permit winding the wire on one side only. The heating elements were put in position and bonded to the inner cylinder wall with Duco cement. The cylinder was held together by a leather thong, the tension of which was adjustable. Holes were drilled through both end plugs and the wooden separators, and the leather thong was passed through the bottom plug and held by a steel pin at the lower end. The other end of the thong was passed up through the separators and attached to the head of a bolt, the threaded shank of which was held in tension by a wing nut. By tightening the wing nut, the entire apparatus was held securely by a thong of low thermal conductivity.

Temperature control was accomplished by using manually operated variacs on the heating elements of the test section and guard ring plates. In this manner, the cylinder could be operated at any desired temperature. Temperature measurement was made by mounting thermocouples on each section. The thermocouples were made from B & S No. 36 copper-constantan wire and were

surface mounted, one in the center of each section plate, and two pairs to measure the gradient across each separator. Insulation was accomplished by coating the cylinder plates with an insulating varnish. All leads were brought to the top plug and were bonded in place on the outer surface of the cylinder with Duco cement. The guard ring brass cylinder gave results which were reproducible with an error of less than 3 percent when used in a constant temperature room.

Guard Ring Aluminum Cylinder

The increased interest in studies of wet-cold clothing assemblies stimulated the development of the Guard Ring Aluminum Cylinder (Figure XII). This cylinder was designed to permit suspension from the cantilever beam of an electric strain-gauge scale (Figure XIII). With such a small, lightweight cylinder, it is possible to record automatically the rate of moisture loss from a wet fabric or clothing assembly while a thermal-insulation measurement is in progress. It was also contemplated that the cylinder might be suspended in a new wind tunnel (Figure XIV) to measure the effect of air movement on the thermal insulation, and therefore, its dimensions were planned accordingly.

This cylinder was constructed from aluminum tubing with a wall thickness of .095 inch and an outside diameter of 3.0 inches. The test section plate was 5.0 inches in length; the upper and lower guard ring plates were each 2.5 inches. The end plugs and separators were made from balsa wood. End plugs were cut from stock 3"x2"x5/8"; the separators from 3"x3"x3/8" stock. Both were turned to proper shape on a lathe. The heating elements were made by bonding B & S No. 30 constantan wire (3.3 ohms/ft.) to cotton duck fabric with Duco cement in a grid pattern. An electrical resistance

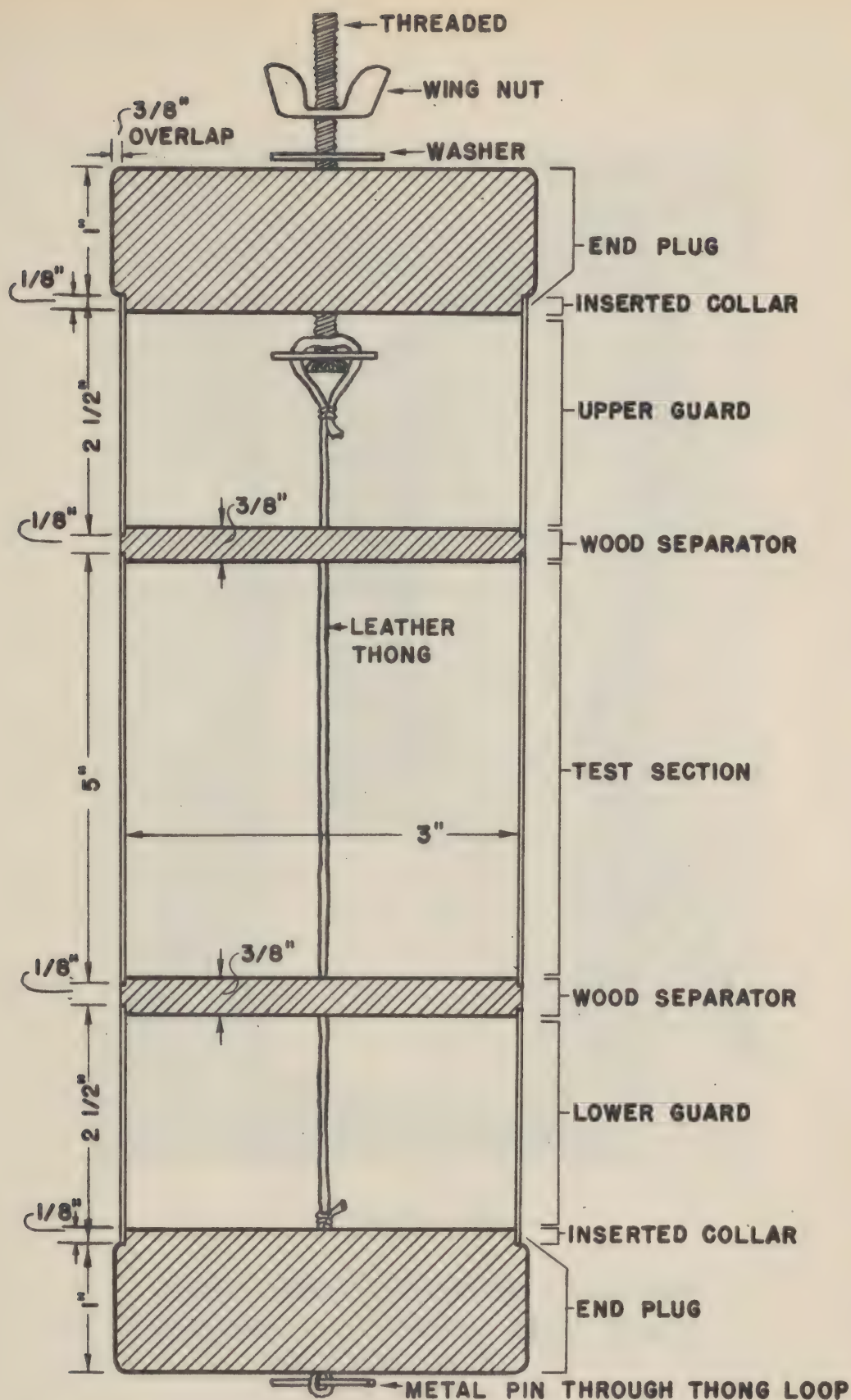


FIGURE XII
 GUARD RING ALUMINUM CYLINDER



FIGURE XIII

GUARD RING ALUMINUM CYLINDER
HANGING ON STRAIN GAGE SCALE



FIGURE XIV

**GUARD RING ALUMINUM CYLINDER WITH SERGE FABRIC UNDER TEST
IN CLOSED CIRCUIT WIND TUNNEL**

of 320 ohms was obtained for the test section and 160 ohms for each of the guard rings. To accomplish this, it was necessary to lay the wire 32 continuous strands per inch on the cloth. Inner surfaces of all plates were covered with three coats of Bakelite varnish, each coat being baked on at plus 250°F. for 1 hour. To insure adequate insulation, bonded Mica sheeting was cut to fit the inner circumference of the plates which together with the heating element was then put in place, using additional Bakelite varnish for bonding. Heating element leads were brought up through holes in the separators and end-plugs to terminal-strips on the top.

Control of cylinder temperature was accomplished by mounting Thermistors on the test section and guard ring plates. Each Thermistor (electrical resistance of 810 ohms at plus 75°F.) was imbedded in a groove which was coated with Fleck's perfected cement for insulation and a silver-mercury amalgam completed the mounting to give a level surface (details for mounting are given under the description of Guard Ring Flat Plate No. 3). One Thermistor was used for each section.

Thermocouples of B & S No. 30 copper and constantan wire were used for temperature-measurement purposes, two for each section. These thermocouples were imbedded in a manner similar to that used for the Thermistors. Leads were brought to the top plug through the inside of the cylinder.

The entire cylinder was held together securely by using a leather thong arrangement (details given under description of the Guard Ring Brass Cylinder).

A suitable terminal-strip was made by nailing copper strips $1/8'' \times 1/2''$ around the outer edge of the top plug and soldering all leads to one end of the strips. Insulation tests conducted after assembly was completed, indicated resistances in excess of 5,000,000 ohms. As a final step, the cylinder was covered with two coats of flat black paint.

Bronze Foot

Early measurements on footgear insulation were determined by utilizing a copper foot. However, it was felt that although the results were useful, the copper foot was a crude instrument and required improvement. The Bronze Foot (Figure XV), conforming as closely as possible to the contours of the human foot was cast from life, the model being one of the enlisted men of this laboratory. The casting was constructed in two sections which were fitted together by means of a Roman joint so that either the whole casting or the toe and instep section might be used.

The Bronze Foot was heated by means of B & S No. 30 constantan resistance wire (3.3 ohms/ft.). Two 100-foot lengths of wire were coated with insulating varnish and wound into a coil. The varnish was applied by drawing the wire through a section of Pyrex glass tubing which contained the hot varnish - Bunsen burners placed beneath the tubing provided the necessary heat. The heating was adjusted to keep the varnish in a fluid state but was not sufficient to char the cotton insulation on the wire. As the wire emerged from the end of the tubing it was wound about a length of wooden doweling (1/2" diameter) to form a continuous cylindrical coil. Both of the 100-foot lengths of wire were treated in this manner. When completed, the coils were connected in parallel and loosely distributed throughout the interior of the foot. Seventy feet of one coil were placed in the toe and instep section of the foot and the remaining 30 feet plus the second 100-foot coil were spread throughout the ankle and lower calf section. This arrangement was found to give the most even heat distribution. The resistance of the two coils in parallel was 162 ohms. Power was supplied from a 110-volt A.C. line through a variac.



FIGURE XV

BRONZE FOOT, BARE, SET UP FOR OPERATION
WITH THERMISTOR ELECTRONIC THERMOREGULATOR



FIGURE XVI

BRONZE FOOT WITH SKI SOCK COVERING UNDER TEST

Six B & S No. 30 copper-constantan thermocouples were mounted on the outer surface of the foot in the following areas:

- | | |
|---------------------|--|
| 1. Tip of great toe | 4. Back of Heel |
| 2. Instep | 5. Anterior tibial portion of the lower leg |
| 3. Sole | 6. Posterior tibial portion of the lower leg |

Duco cement was used to hold these thermocouples and their lead wires in position. All leads were brought to the top of the Bronze Foot and connected to a 6-terminal Jones' plug. Temperature control was accomplished subsequently by mounting a V-611 Thermistor (810 ohms at plus 75°F.) on the instep of the foot. Excessive heat loss through the top end was prevented by plugging it with felt covered by butyl-treated nylon.

The Bronze Foot was normally operated at a temperature of plus 90°-100°F. in a constant temperature room. When dry sockgear was placed on the foot (Figure XVI) any two thermocouples would not differ by more than 1.0-1.5°F. However, when wet sockgear was tested a considerable difference in the thermocouples was noted; this spread was similar to that encountered in physiological testing. Test results using the Bronze Foot were expressed as an "insulation index". One unit in this system was the insulation provided by the combination of one ski sock and one cushion-sole sock. This method of expressing insulation values was used since the experimental data was difficult to translate into the conventional Clo units.

CHAPTER IV

EVALUATION OF HOT-CLIMATE CLOTHING

Evaluation of clothing for hot climates includes so many ramifications and constitutes such an important part of the Laboratory's program that separate consideration is warranted. The descriptions of testing procedures and techniques presented in this chapter were excerpted from Report No. 80, "Uniform, Jungle".

The results of the Jungle Uniform study were divided.....as follows:

- (1) Phase I - Drying Rate - i.e., amount of water lost per unit of time.
- (2) Phase II - Thickness - unused and dry; used and wet.
- (3) Phase III - Dragometer Measurements - an objective study of the effect of drag upon the skin.
- (4) Phase IV - Solar Radiation - a study of differences when garments are exposed to radiant energy.
- (5) Phase V - Physiological Heat Load and Comfort, Technique.

Phase I - Drying Rate

Since the drying rate, i.e., the amount of water lost per unit time, undoubtedly affects the comfort and heat load of jungle uniforms, it must be considered in any decision concerning their desirability. Therefore, the drying rate of each of the ten types of uniforms was determined by a series of tests conducted in the Jungle Chamber under simulated jungle conditions. Additional experiments, conducted under customary laboratory conditions, served to check the conclusions of the Jungle Chamber study.

Ten uniforms, comprising jacket and trousers, each of the same size, were weighed separately when dry. Each was then immersed in water for 30 minutes, removed, and put on a line for 5 minutes to let the free water run off. Following this procedure, the garment was weighed and placed on the drying line. Weights were taken every 30 minutes for a period of 7 hours. Special care was exercised to insure that all uniforms were in a similar position throughout the test.

In order to provide an adequate check on the constancy and accuracy of the test results, two separate determinations of drying rate were made in the Jungle Chamber under the jungle conditions which were constantly maintained (dry bulb 90°F., relative humidity 85 percent) as well as at three ambient conditions in the Chemistry Laboratory. Although the temperature and humidity in the Laboratory varied somewhat from day to day, the results were comparable. When reviewed in relation to those obtained from the Jungle Chamber tests, an appraisal of the drying rate under different conditions may be gained.

Phase II - Thickness, Wet and Dry

Fabric thickness is a factor which is believed to influence the heat load imposed by garments. In order to determine the extent of this influence, a systematic study of the thickness characteristics of the ten types of jungle uniforms has been made by means of an Ames Compressometer. In the first test, one pair of trousers of each type of uniform was selected. With this single garment, a series of ten readings was made with each of six different loadings of the compressometer foot, i.e., one reading was taken at each of ten different sites in the garment with the following pressures: 0.10, 0.20, 0.35, 0.50, 0.75, and 1.00 pounds per square inch, respectively.....After these data had been collected on new, dry fabrics, the same procedure was repeated on previously used pieces of cloth which had been soaked for 5 minutes in a solution of artificial sweat (Water 99.46 percent, Sodium Chloride 0.3 percent, Urea 0.04 percent, Lactate 0.2 percent) before their thicknesses were determined.

Phase III - Dragometer Measurements

Although the comfort of a jungle uniform is closely associated with the amount of drag on the skin, the only means, thus far, of obtaining information relative to this aspect has been through subjective reactions elicited by interviews. Such reactions, however, may differ from objective information and in order to increase the scope of the study, an attempt has been made to collect objective as well as subjective data. These have been collected and correlated.

The objective determination of drag was made possible by devising an instrument known as the Dragometer. Drag, like traction in footgear, comprises so many variables that measurements are non-specific and results

comparative. The Dragometer, nevertheless, supplies information not hitherto available and possesses certain intrinsic merit.

This instrument consists of three principal parts:

(1) a chair frame which enables the subject to sit with the back flat and as perpendicular as possible; (2) a scale, pulley-type, with a hook on one end and a water container on the other; (3) a water-filled pipette with sufficient rubber tubing to reach the water container. The chair is placed in front of the pulley and the subject is seated so that his back will be adjacent to the hook of the pulley. The test area of the subject's back is marked with adhesive tape so that the position of the textile under test will be constant. A swatch, 8 inches square, of the test fabric is saturated in synthetic sweat (Water 99.46 percent, Sodium Chloride 0.3 percent, Urea 0.04 percent, Lactate 0.2 percent). The swatch is attached to the hook of the pulley, and placed on the subject's back. The pipette is opened and water allowed to flow gradually into the container until the fabric slides along the back of the subject. The contents of the container is then emptied into a graduate and the amount of water noted. Water is used as a unit of measure for two reasons; (1) the gradual increment permits an accurate determination of the breaking force; (2) the flow of water through the tubing supplies a constant and even pressure. In order to insure better control each type of fabric was tested several times and an average taken. These determinations were repeated on successive days on a small number of subjects. All of the experiments were performed in the Jungle Chamber under a simulated jungle environment. With this technique, measurement of the breaking force required to initiate movement in swatches of various types of fabrics of identical size, i.e., comparative drag, has been achieved.

Phase IV - Solar Radiation

Although it is an accepted fact that the color of a uniform causes a variation in radiation absorption, the extent of its effect upon imposed physiological heat load has not been definitely determined. Since the measurement of heat load cannot be controlled as precisely as the measurement of radiation, such an investigation is a difficult one. The major obstacle is that heat load measurements are determined for human beings subject to many bodily changes and radiation is measured on inert material. The problem, therefore, was studied from two aspects: (a) a determination of the reflection of total sunlight by the fabrics of the test uniforms and (b) a comparison of the heat loads imposed by uniforms of the same fabric but of different color.

The measurements of the reflection from the fabrics were made by Dr. Irving F. Hand of the Solar Radiation Section, Weather Bureau, United States Department of Commerce. His report follows:

'A frame over which we could place trouser material at normal incidence to the pyrliometer was placed in such a position that when the pyrliometer was oriented 180° from the position used for normal incidence measurements, the pyrliometer could be at normal incidence to the fabrics. We first read the radiation from the sun and sky with the pyrliometer pointing directly towards the sun. The pyrliometer then was turned 180° so that it pointed at right angles to the plane of the material under test. As the distance was constant, we obtained relative, although not absolute, values of the albedoes. The radiation from the sun and sky was obtained immediately before and immediately following the series of albedo measurements. All readings were obtained close to solar noon and the difference between the first and second readings on the sun was very small. Nevertheless, we plotted these readings and used interpolated values to compare against the albedo measurements. All values then were converted to what we consider close to true reflection coefficients by multiplying them by the ratio of the true albedo of Cotton Khaki, 8.2 oz. as obtained by L. B. Aldrich of the Smithsonian Institution to the albedo obtained in the manner just described.'

The comparative study of heat load can be described as follows:

The actual testing required a two-hour period on each of two successive days. On both of these days the subjects sat in the full glare of the lamp section for a period of two hours. The weight loss during this period and the final rectal temperatures and pulse rates were determined by standard jungle testing procedure. All test subjects were exposed at the same time. The experimental technique, conditions and subjects were controlled by dividing the soldiers into two groups and assigning Uniform No. 5 or No. 12 to each soldier the first day. On the second day the types of uniforms were exchanged.

Phase V - Physiological Heat Load and Comfort - Technique Environmental Conditions

The 'Standard' jungle conditions selected for this study, dry bulb, 90°F., relative humidity, 85 percent were those recommended at a special meeting at the National Academy of Science. These conditions approximate those found in Burma during July.

In the Laboratory Jungle Chamber it has been possible to provide for a dry bulb of 90°F., a wet bulb of 86°F., with a resultant relative humidity of 85 percent and to maintain the temperature of walls, ceiling and floor at the existing ambient temperature by circulation of hot water through radiant panels. During the course of the experimental day the dry bulb rarely varied more than 1°F. and the wet bulb seldom more than 0.75°F. The variation in humidity was less than ± 2 percent. The wind velocity in the majority of studies was 1.5 mph. Although these conditions do not approach the critical limits established by the Armored Medical Research Laboratory, they represent severe jungle environment.

Experimental Subjects

In all studies, from six to ten soldiers were utilized as experimental subjects..... Prior to entering upon this study, the soldiers were physically conditioned by two weeks of field exercise, after which they were acclimatized to jungle conditions. The initial data were collected after approximately 11/2 months of Jungle Chamber exposure. During this period each soldier spent at least 3 hours a day, 5 days a week in the chamber. Of the 3 hours, at least one was spent in exercise. A furlough of 1 week was granted periodically to the test subjects which was justifiable since lack of exposure to hot environments for this period of time does not significantly reduce acclimatization.

Experimental Procedure

The procedure followed to obtain the data presented in this study was standardized before actual testing was initiated. An identical routine has been used in all studies reported. It is described briefly as follows:

(1) After entering the chamber, each soldier spent the first hour at liberty. During this time, dressed or undressed according to his own taste, he was allowed to do as he desired insofar as his wishes did not include exercise. Reading, writing, playing cards, and similar activities were permitted.

(2) After the initial hour of adjustment, the subject was weighed to an accuracy of ± 5 grams, the rectal temperature determined with an accuracy of 0.1 degree by means of a clinical thermometer, and the pulse recorded by auscultation. Immediately thereafter the exercise period started. Each soldier spent 60 minutes walking on the treadmill at the standard rate of 3.5 mph. No rests were allowed and no measurements of any sort were recorded during exercise. No water was given during this period.

(3) As soon as the 1-hour march had been completed, each subject stepped off the treadmill, at which time his pulse (taken for 30 seconds and multiplied by 2) and rectal temperature were determined. Thereafter, he was wiped dry of all perspiration and weighed.

(4) If the soldier had been wearing a uniform, it was weighed before and after exercise.

(5) After these physical and physiological measurements were completed the soldier again spent 1 hour in the chamber. As before, he was allowed to do as he pleased. During this final period a majority of the subjects spent their time sleeping.

(6) Finally, the subjective reactions of the test subjects to the adequacy and performance of the garment were determined by interview, and tabulated.

With the data thus compiled, an adequate indication of the heat load during the period of exercise was obtained. The initial pulse and rectal temperatures were of value only in disclosing the fact that the subject was in a relatively basal state. In appraising the severity of the exposure, only the values at the end of the exercise period were considered. The variance between the initial and final weights reflects the total sweat loss which is probably the best indication of heat load. In addition, the initial weights of the garments, their moisture uptake, and the percentage of total perspiration taken up by them may be computed.

The questions which formed the basis of the interviews were selected by the soldiers. Since little was known concerning pertinent subjective reactions to the jungle uniforms, it was felt that definitive indications of the significant features should be first obtained. In order to accomplish this, each subject was asked to write daily an essay relative to his reaction to the assembly worn during the preliminary testing periods. These essays were analyzed to determine which topics recurred frequently. It was determined that general desirability, skin sensation, drag, ventilation, and heat sensation were usually the features discussed. These considerations, therefore, were made on the basis of all interviews.

The fact that only two subjects can march simultaneously on the treadmill necessarily increased the complexity of the experimental procedure. Under these conditions, to insure proper control of the experiment,



TESTING IN THE JUNGLE CHAMBER

only two uniforms could be considered in the same experiment. In all of the studies reported herein each of the two subjects marching simultaneously on the treadmill wore a different uniform. On the following day these were exchanged so that the two soldiers marching together rotated through the gear. Such a procedure was laborious since the several possible combinations of uniforms, about which information was sought, had to be compared in groups of two. Nevertheless, this was the only means of assuring adequate control in an experiment such as this one.

Control Values

At least once a week control experiments were performed in order to check the acclimatization of the subjects and to insure the accuracy of experimental results. In these control studies, the procedure differed only in the type of attire; the subjects wore Shorts, Cotton, instead of a test uniform. The values obtained were compared with those previously achieved under the same circumstances. Excessive variation was investigated and controls repeated until satisfactory values had been attained.

CHAPTER V

MEASUREMENTS OF MANUAL DEXTERITY PROVIDED BY HANDGEAR

In this laboratory, tests of manual dexterity have been utilized for two purposes:

- (1) To supply an index of the thermal insulation of handgear.

Manual dexterity is dependent, to some extent, upon the coldness and stiffness of the fingers and hands. However, the design of the handgear provides an additional variable which exerts an influence upon manual dexterity; therefore, this index is of value only when the handgear is of similar design and construction.

- (2) To investigate manual dexterity per se. Care must be taken to eliminate the differences in thermal insulation by designating an appropriate ambient temperature, and thus test only the ease and facility with which the glove or mitten allows the subject's hands or fingers to operate. Even in the initial tests of dexterity, it was realized that one test was insufficient to investigate thoroughly every aspect of the problem; therefore, several different tests were conducted as follows:

There were five procedures followed in the Cold Room by the wearers of the Rayon Gloves: (1) A box of 2 dozen carriage and stove bolts of assorted sizes were used first. The purpose was to screw on the nuts, then unscrew them and put them back in the box. The small stove bolts could be handled with almost the same precision as at room temperature. The subjects would stop for 1 or 2 minutes to rub the fingers when working on the larger carriage bolts, but this was not necessary when screwing the smaller stove bolts; (2) A typewriter was used readily. Since the typewriter was not oiled for such low temperature, the keys responded slowly, but if a properly prepared typewriter had been available, a skillful typist could have made at least two-thirds the speed as would have been possible at warmer temperatures; (3) The manual of arms with a Garand Rifle was next executed. The rifle, wood or metal parts, could

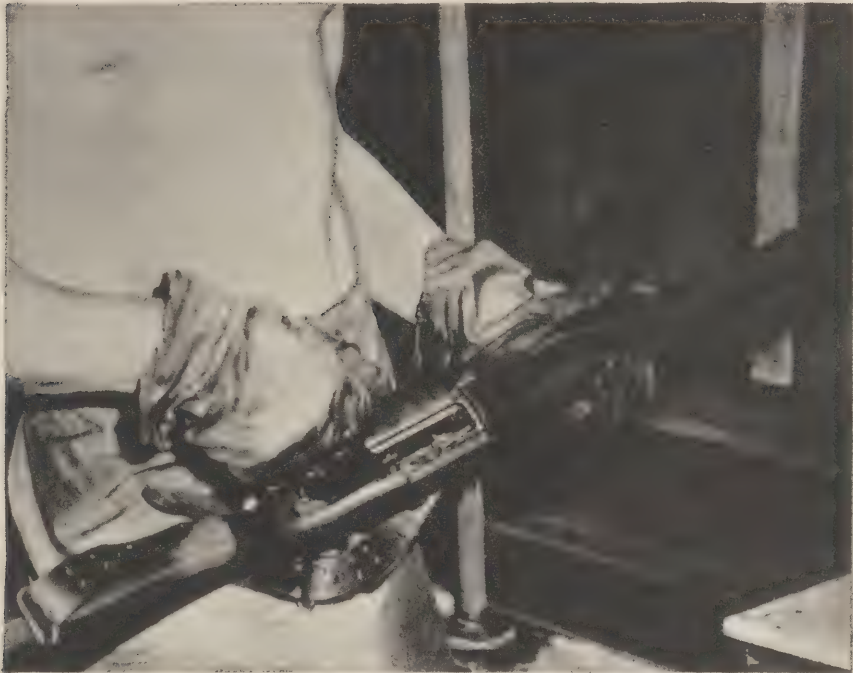
not be gripped tightly for more than 90 seconds without cooling the hand off rapidly. If the maneuvers were done sharply, however, it was possible to avoid any long continuous contact with the rifle and extreme cooling of the hand did not result; (4) The laces of a felt boot were inserted and removed readily. This was the warmest of all operations and could be performed as dexterously as at room temperature; (5) Finally, large tools, wrench, nail claw and a large bolt were handled. (Provisional Report, 20 July 1943)

Several difficulties were immediately apparent in these tests. First, it was revealed that some types of equipment, such as a typewriter, were not suited for use in the Cold Room. Second, the learning factor in some of the tests was a variable hard to eliminate. And third, the handling of the rifle and tools was practically valueless as a dexterity test because the hands quickly cooled when the handgear came into contact with the metal surface; therefore, another test was designed as follows:

It is suggested that two test boards be used. One of each should be provided each subject. The boards are to be constructed as follows:

Two $7/8$ " hard wood rectangular boards about $10" \times 12"$ with symmetrically placed holes large enough to take $5/8" \times 2\frac{1}{2}"$ machine screws, should be provided. One of these should be supported in a vertical position by two cross pieces. The operation should consist of approximating the boards, inserting the bolts and applying the nuts. One ordinary washer and one spring washer should be applied at either end of the bolts. The nuts are to be tightened with an open end wrench until spring washers are flat. Boards should be supplied each subject so that all can work simultaneously.

In order to provide for a test of a higher degree of dexterity a similar device constructed of $1\frac{1}{2}"$ Masonite and in the form of two loose discs $3\frac{1}{2}"$ in diameter with six regularly spaced holes, shall be provided for each subject. The holes shall be large enough readily to accommodate 6-32 machine screws. The screws shall be $7/8"$ in length. The operation is to be the same as that already suggested, except that wing nuts and washers are to be fitted to the bolts. The time shall be recorded. These tests shall be performed at room temperature and also at the experimental temperatures. ("Specifications for Testing Handgear", Ferry and others, Provisional Report, 25 November 1943)



TESTS FOR MANUAL DEXTERITY

It is suggested that a learning factor is present in this test and proper recognition of this fact must be made; however, a degree of success was attained with this test as seen from the following excerpt:

The choice of a test for measuring manual dexterity is a difficult one. A compromise must be made between simplicity and simulation of actual field conditions. If the test is too simple, it fails to measure dexterity in doing a task similar to that required in the field, while if the test is too difficult it either entails a long practice period to obtain proficiency or else depends too heavily on the soldiers' previous training and experience. It is felt that the present test, involving the removal and replacement of six 3/4" bolts in two circular boards, is sufficiently simple that only slight practice is necessary, and at the same time approximates hand and finger movements frequently required in the field.

(Provisional Report, 21 January 1944)

For the remainder of the testing program, the nut-and-bolt assembly test was employed as an index of manual dexterity. When it became obvious that certain aspects of the problem were not receiving proper recognition, a memorandum formulating the principles governing this field of study was prepared. A summary follows:

(1) One type of test is not sufficient. The hand is a very flexible instrument and no single test can do justice to a glove or mitten. A minimum of four varieties of action is necessary to reveal important differences.

(2) Tests in which little, if any, learning is required are superior. The difficulty with certain nut-and-bolt tests, for instance, is that subjects must learn new movements before testing can be initiated.

(3) The timing of the tests should be as accurate as possible, preferably with a stop-watch timed to 1/10 of a second. This procedure should be followed even if individual runs are necessary.

(4) A distinction must be made between manual dexterity and finger dexterity. Tests which illustrate manual dexterity do not necessarily illustrate finger dexterity. Different tests must be devised for the two types. Included in this memorandum were several suggested tests based upon these principles:

(1) Finger-dexterity tests

- (a) A test necessitating the subject's picking up and placing checkers in holes on a board.
- (b) Buttoning buttons of various sizes. (This provides a fairly complicated movement which requires no new learning.)
- (c) Stringing large wooden beads on a wire.
- (d) Placing shot in a small diameter tube.
- (e) Lacing two pieces of cloth in the manner of lacing shoes.

(2) Manual-dexterity tests

- (a) The standard nut-and-bolt test used in the Climatic Research Laboratory.
- (b) Dealing a deck of cards to four people.

CHAPTER VI

WATER-REPELLENCY TESTS FOR CLOTHING

Testing of water-repellent clothing was initiated in outdoor tests during periods of precipitation. The difficulties encountered, however, (impossibility of reproducing test conditions, difficulty of rotating test items, etc.) soon necessitated the transfer of testing of this nature into the test chambers. The first of these tests (in the Jungle Chamber) is described as follows:

The second experiment was conducted in the Jungle Chamber. Ten soldiers were exposed to a driving rain, propelled by a 25 mph. wind for a period of 8 minutes. The water was driven horizontally and struck upper and lower portions of the body with equal intensity. Thus, water penetration of trousers and jackets was being studied under similar conditions.
(Provisional Report, 12 April 1944)

As in many of the previously described test procedures, the development of water-repellency testing resulted from alterations and improvements necessitated by the constant appearance of new difficulties. One such difficulty is described in the following excerpt; also included is a further description of the testing in the Jungle Room:

In the absence of rain in the out-of-doors, a water repellency experiment was conducted in the Jungle ChamberNineteen men wearing various types of experimental jackets and trousers in addition to the basic clothing noted were exposed to a hard rain driven by a 25 mph. wind in the Jungle Chamber. The experimental clothing, as well as the shirt and trousers worn beneath them, were weighed prior to and at the conclusion of the exposure. The exposure in the Jungle Chamber was 30 minutes. During this time the equivalent of 1.0 inch of rain was assumed to have fallen. It will be recalled from the previous report that less than 0.2 inch of rain is insufficient to give any preferential data on the items. One inch has been selected as the equivalent of a reasonably heavy torrential downpour.

One difficulty encountered in previous water-repellency experiments was penetration of water past the collar opening and through the front opening of the field jacket with consequent wetting of the underlying clothing by means other than direct penetration of the fabrics. This was minimized in the present experiment by wearing the experimental hood for the M-1943 field jacket, and keeping the hood tied and buttoned as snugly as possible. The hood was reasonably effective in keeping water from running down the neck of the wearer, but practically all men noted that a small amount of rain entered at the back of the neck, where the hood tended to blow up from the collar of the jacket. Leakage of water through the front of the jacket continued to be the major mode of entrance of water through the jacket.

The conditions were somewhat better for the trousers, since no water leaked through the fly opening or the waist closure of the trousers because of the protection offered by the overlying jacket.
(Provisional Report, 5 May 1944)

In addition to the test program on water-repellent jackets and trousers, the comprehensive program included the study of water-repellent sleeping bags and cases. Again problems appeared which necessitated special attention; a few of these, as well as test procedures, are described in the following:

Trial runs of overhead rain have been conducted in the Jungle Chamber during the past three days. A new and improved rainhead has been installed so as to provide a fairly gentle overhead rain. This is a separate apparatus from that used for horizontal driving rain such as is used in the water-repellency experiments on field jackets and trousers. The temperature of the room on the several testing days varied from plus 51° to plus 55°F. The temperature of the water after the first few minutes was plus 59°F. Although the Jungle Chamber is able to reach a minimum temperature of plus 40°F., it is not possible to reach this minimum temperature at the same time that a rain is falling at a significantly higher temperature. The principle interest in the current experiments was the moisture uptake of the sleeping gear rather than the tolerance time of the subjects at a specific exposure temperature. An excessively heavy rain was used; the amount was much greater than would be encountered in the field except in most unusual circumstances in isolated regions of the world.

Three soldiers participated. They were clothed in woolen undershirt, woolen drawers and cushion-sole socks. Each sleeping gear consisted of two Bags, Sleeping, Wool, and a protective case. The protective cases were of three types; (a) water repellent; (b) water repellent upper and water impermeable lower; and (c) water-impermeable, respectively. These were rotated among the test subjects. On the first test day the cases were used without any modification of design of the opening. On the second day the opening of each of the cases was covered by a wide strip of adhesive tape, applied by an assistant after the soldier had entered the bag and had closed the opening in the customary manner. The application of tape is not realistic but was done in an effort to prevent excess leakage. It served its purpose only moderately well as the tape began to pull away from the cases in small isolated areas before the experiments were finished. On the third day, a flap made of the same fabric as the case was added to the area over the opening. It was 12 inches wide and extended up to the lower portion of the face opening. One edge of the flap was sewn to the border of the opening, the other edge was fastened by snaps to the top of the case. This additional protective flap was fastened in place by the occupant and outside assistance was not necessary. On each of the days, the face opening of all of the cases was reduced to a minimum. This did not keep out all water but the opening was so small that only a relatively small percent of the total water that entered the case was believed to have entered through the face opening. The great bulk of the water entered through the closure slit of the case or through the fabric. This conclusion was the consensus of opinion of the occupants and was verified by inspection.

The rain provided was a very heavy one. The quantity of water was equivalent to a rainfall of approximately 2 inches per hour. Most of the experiments were continued for 2 1/2 hours. In two experiments when the test was terminated prematurely, the shorter exposure time was not believed to have been a factor in the moisture observations. Since these were only trial runs the heavy rainfall was provided so that information would be available regarding the effect of the maximum quantity of water. In subsequent experiments it is planned to supply much smaller quantities of water. The temperature of the water in the lower temperature range is determined by the temperature of city water in the Lawrence water system. In the winter time it will be somewhat colder than 59°F. In the summer it will be

Outdoor Rain Court



Rain Court

TESTS FOR WATER REPELLENCY

somewhat warmer. The higher temperature range need not concern us, however, since steam heat for the rain water is being installed and within a few days it will be possible to have the full quantity of rain heated to any desirable temperature above 50°F. Thus, a tropical rainfall with a tropical rain temperature will be available. In the Jungle Chamber, the fall of rain is fairly uniform over an area 16 by 16 feet. In this experiment, the sleeping bags were placed on the false wooden floor and it was not possible for puddles of water to form. (Provisional Report, 13 May 1944)

Water-repellency tests of sleeping gear must necessarily include supplementary tests; another phase comprises a study of the resistance to ground moisture. A test of this nature is described as follows:

The investigation of the comparative water-repellent properties of the three types of sleeping bag cases has been continued during the past three days. In the first experiment studies of the protection provided against a heavy overhead rain were pursued. In this report data are presented concerning the resistance each type of case offers to the passage of moisture through its under surface while resting on wet terrain.

The conditions necessary for this type of experiment involved the preparation of an under surface similar to wet, muddy ground. To do this, shallow metal pans of an appropriate size were filled with a 4-inch layer of sand. This sand was later soaked with a sufficient amount of water to allow for small amounts of free fluid on its surface at all times. Enough water was present so that wherever pressure was applied a shallow puddle of water formed immediately. Thus, throughout the experiment each case was resting in a pool of free water. No overhead rain was used. (Provisional Report, 26 May 1944)

The artificial exposure conditions in the Jungle Chamber prevented precise duplication of natural conditions. Insufficient ceiling height and improper rainheads did not permit the reproduction of natural rainfall; therefore, in the Fall of 1944, an attempt to rectify these defects was described as follows:

The conditions sought for the present study were those of a steady, gentle rainfall. These were accomplished by using the new type spray head recently shipped

from Washington in an outdoor raincourt. The free fall of the rain was approximately 24 feet. Since the device was installed in the out-of-doors without wall protection, the fall of water was affected by gusts of wind. In order to remain continually in the rain area a certain amount of movement was required. Throughout the entire period of exposure the rain consisted of extremely fine droplets. The actual amount varied somewhat from spot to spot because of the shifting wind but it averaged about 1.5 inches per hour.
(Provisional Report, 9-10 October 1944)

Even with an outdoor Rain Court, it was still difficult to maintain constant test conditions because the wind was a variable factor. However, with the acquisition of a large, high-ceilinged room (the Rain Court) and with the installation of adequate rainheads, test conditions could be varied and reproduced at will.

As more efficient water-repellent fabrics were produced, more rigorous test procedures were required. One effort in this direction is described in the following:

Since the procedure of walking in the rain did not develop large differences in the moisture accumulation of the underwear, a test of a more rigorous nature was planned. An attempt was made to break down the resistance to water uptake and water penetration by means of pressure applied to the fabrics when wet. With a rainfall of 1 inch per hour, test subjects at regular intervals were required to crawl on the wet floor of the rain chamber and to sit on the floor and rub their trousers with their hands. Eight cycles of this activity were pursued during each 3-hour exposure. This involved a total crawling of 400 feet per man per period. It was apparent that immediately upon lying on the wet floor the trousers took up considerable moisture, particularly in the region of the thighs. After subsequent periods of crawling and rubbing, the trousers became increasingly wetter and after 3 hours both trousers and drawers appeared to be well saturated.
(Provisional Report, 9-10 April 1945)

The inclusion in the testing program of fabrics of greater efficiency and items of greater variety necessitated much investigation before a test procedure could be standardized. The amount of preliminary work necessary is shown in the following excerpt:

The investigation of the water repellent and water absorption characteristics of hoods required a considerable amount of preliminary experimental work in order to determine the optimum testing conditions which would yield well differentiated moisture gain data among the test items. The exposure of garments in the Rain Chamber may be influenced by at least two variables, i.e., (1) the intensity of the rainfall, and (2) the amount of rubbing or pressure exerted on the fabric. The combinations of rainfall intensity and rubbing, therefore, permit four testing procedures to which garments in this test were exposed. These are as follows: (1) one inch per hour rainfall without rubbing, (2) three inches per hour rainfall without rubbing, (3) one inch per hour rainfall with rubbing, (4) three inches per hour rainfall with rubbing. The water repellency of the seven types of hoods have been tested under each of these conditions.

Initially the testing procedure consisted of allowing nine test subjects to walk in 1 inch per hour rain without rubbing the hoods. Weights of the visorless caps and hoods in this test, as in all succeeding tests, were taken at half-hour intervals over a period of 3 hours. The results of this test showed an average gain in weight of 3 or 4 grams for all of the caps worn under the hoods with no indication of any leakage.

A more severe test was then instituted with the test subjects exposed to 3 inches per hour rain. The hoods, as in the previous test, were not allowed to come in contact with any object which might promote leakage by pressure. The results of this test were essentially identical with the results of the test involving 1 inch per hour rain in that no leakage occurred and the average moisture accumulation in the cap under the least satisfactory hood did not exceed five grams.

With the failure to induce leakage under these conditions, exploratory studies were planned in order to investigate the influence of the cap worn under the hood upon the repellency characteristics of the hood itself. In pursuit of this phase, four types of caps

were used: (1) Standard water repellent treated caps, (2) Standard untreated caps, (3) untreated HBT caps dipped in soap solution to promote water absorption, and (4) caps made for the test out of towelling. All caps were without visors and completely covered by the hood so that any appreciable gain in weight of the cap could be attributed to hood leakage. All four caps and all seven hoods were then tested under 1-inch and 3-inch per hour rainfall intensities and without rubbing. The results were similar to the previous experiments and no leakage of the hoods was detected.

The effect of exposure to excessive rainfall was investigated next and the seven types of hoods were exposed to the 12 to 15 inches per hour of rain produced in a driving wind in the All Weather Chamber. With a 1-hour exposure to rain of this intensity, the weight increase in the caps varied from 2 to 5 grams; no leakage was observed.

At this point it became apparent that a new type of test had to be devised if the comparative repellency of the hoods was to be determined. Up to this time the significance of pressure and rubbing as factors in promoting leakage had not been fully appreciated for it was considered that the terminal velocity of rain was sufficient to cause some penetration of water through the water repellent fabric. It now appeared, however, that the water-repellent treatments were capable of withstanding passive exposure to rain and that it required traumatic methods to develop substantial leakage. It also became apparent that mere exposure to moisture did not lower the repellency of hoods to any appreciable extent as had occurred with earlier water repellents. Note was made of the amount of rainfall to which each hood was exposed, and after submitting to 36 inches of rain, it was found that the hoods reacted as they had previously in not permitting water penetration. This fact was verified with hydrostatic tests on the hoods before and after exposure to 36 inches of rain when there was found to be no significant decrease in hydrostatic values.

Investigation was next made of a satisfactory method of rubbing the hoods. Initially, test subjects were required to walk in the rain and to rub their hoods 10 times every 15 minutes. This procedure created some leakage but not of sufficient quantity to produce clear-cut difference. The process was then increased in severity so that the cycle of rubbing 10 times with both

hands was repeated 4 times every half hour. This technique of a rubbing cycle every $7\frac{1}{2}$ minutes was used for the remainder of the tests and has proven satisfactory. The rubbing was accomplished in a similar manner by each subject, care being taken to keep a uniformity of method. (Provisional Report, 11-13 June 1945)

An example of another new test procedure, conducted outside of the Rain Court, is revealed in the testing of water-repellent mitten shells:

After the shells had been treated by each of the three procedures, it was necessary to develop a testing technique which closely simulated the constant handling of wet objects by the wearer, yet which could be conducted under controlled conditions.....The equipment used consisted of a shallow pan measuring $13'' \times 12'' \times 2\frac{1}{2}''$, a steel cylinder $2''$ in diameter and $10\frac{1}{4}''$ long and weighing $10\frac{3}{4}$ pounds, and a standard issue towel. The towel was wrapped around the steel cylinder which was rolled back and forth in the shallow pan filled with 1 inch of water. Rolling the cylinder kept the mittens in constant contact with the wet towel and pressure could be varied by the person conducting the test. In addition, an attempt was made to keep the thumbs off the towel when the test was being run as failure to do so tended to allow leakage at the seams.

The testing technique consisted of rolling the cylinder back and forth for a 20-minute period while wearing one type of shell on one hand and another type on the other. Standard Inserts, Trigger-Finger, M-1943 were worn on both hands. To cancel out differences in pressure between the hands, a second 20-minute run was made with the shell types reversed on the hands. Weights of the shell and insert were obtained both before and after the test to determine the moisture pick-up of each. Therefore, pairs of any two types could be compared in the following manner:

	Right Hand	Left Hand
First Run	Type I	Type II
Second Run	Type II	Type I

With four types to test (three treated shells and the standard) there were six possible combinations and during the testing of all six combinations, each type would be run a total of three times by each man.
(Provisional Report, 5-6 March 1945)

It is apparent that standardized procedures suffice in the testing of few of the various test items. The fabric of an item can often be subjected to standardized procedures, but after the fabric has been included in an article of clothing, for example, other factors such as design of openings, the pressure at the shoulders and elbows, and the use of the garment must be considered.

CHAPTER VII

DETERMINATION OF MOISTURE PENETRATION IN FOOTGEAR

The basis of all investigations of moisture penetration in footgear comprised exposure of the test item to conditions of slush, snow, mud, rainfall and water. Actual procedure required weighing the sockgear before and after exposure to determine the degree of penetration. Rotation of test items, as previously described, remained in the test procedure.

Physical tests were often conducted concurrently in an effort to determine the waterproofness of footgear. For example, 1400 grams of water were placed inside each of two different types of shoepac and the shoepacs were then placed in individual pails. At the conclusion of a specified period, the water in the pail was weighed to determine leakage. In a variation of this technique, an empty boot was immersed in a pail of water, remaining in it for a specified period. At the conclusion of the period, the amount of leakage was determined. The defect of these techniques is obvious; there is no flexing of the footgear as that occurring in marching. Flexion greatly increases the rate of leakage.

As remedial action for this problem, it was decided to limit testing to that which would provide a flexing action for the footgear and to extend the exposure as long as possible. This procedure guaranteed a maximum amount of leakage and, therefore, reduced the relative importance of the amount soaked up by the test item. In addition, weights of the test item itself were collected before and after the exposure in an effort to ascertain the quantity of water absorbed by the footgear.

Before actual measures can be recommended to correct leakage in footgear, it is necessary that the site of leakage be determined. To provide

this information, the exposure period was divided into 15-minute periods at the end of which all subjects removed their footgear and visually inspected the sockgear to determine the point at which leakage occurred. Digital inspection oftentimes supplemented and verified this information. Great care was necessary in reporting sites of leakage, especially in shoe testing, because the possible sources are so close that leakage from one source can easily be confused with leakage from another. Experiments were also conducted in which a dye was dissolved in the wading water. White sockgear was worn, and this procedure facilitated the easy detection of sites of leakage as well as the acquisition of excellent photographs for reports.

Hot weather, producing profuse sweating in the feet, necessitated alterations in procedure since moisture gain recorded by the sock weights included an unknown amount of perspiration. The magnitude of this factor was not significant until almost completely waterproof shoepacs were developed. At that time, it was necessary to determine the precise amount of perspiration. To provide this information, the procedure outlined in the following excerpt was developed:

Nine soldiers have completed a study of the effectiveness of both the double and the single sealing strip in regard to preventing moisture penetration through the Yukon seam of the shoepac. Two hours in the morning and 2 hours in the afternoon were spent by the soldiers wading in from 4 to 6 inches of water; this depth was selected since it covers the Yukon seam, but does not extend over the stitched seam in the leather part of the shoepac. Weights were obtained prior to and at the conclusion of each 2-hour exposure in order to ascertain the amount of moisture penetration.

A new method of determining moisture penetration was introduced in this test. In past experiments, the sockgear on one foot, which included one cushion-sole sock and two wool ski socks, was weighed to determine



TESTS FOR MOISTURE PENETRATION IN FOOTGEAR

the amount of leakage through the shoepac. A similar procedure for the opposite foot, on which a dissimilar type shoepac was worn, gave data with which a comparison could be made. However, there were no means available by which segregation could be made of the moisture uptake caused by leakage and that caused by perspiration from the subject's foot. To eliminate this deficiency in the present test, an impermeable sock was worn outside the cushion sock but inside the two wool socks. Then the following weights were obtained for each foot.

(a) Cushion-sole sock and impermeable sock to determine amount of perspiration.

(b) Two wool ski socks to determine amount of leakage.

Thus, for each shoepac the exact amount of leakage, unclouded by extraneous factors, could be determined.
(Provisional Report, 26 May 1945)

The following excerpt describes a series of tests conducted upon a particular type of Shoe, Service; it is included here for informative purposes:

1. Ten soldiers sat with their shoes submersed in 1 inch of water with the standard and experimental items cross-mated on their feet.

2. Ten soldiers waded in from 2 to 3 inches of water for a period of 2 hours.

3. Ten soldiers, wearing shoes on the sole of which had been sealed an impermeable layer to prevent leakage through the nail holes, sat with their shoes submersed in 1 inch of water.

4. Using shallow pans (2' x 6') filled with 1 inch of water, nine soldiers wearing test and standard items from the same manufacturer exposed the shoes for 3 hours during which time they walked approximately 1 mile.

5. In each experiment weights of socks were obtained before and after exposure.
(Provisional Report, 29-30 June 1945)

The second test was conducted in the Rain Court of the Laboratory. During this test, the soldiers walked for 2 series of 4 30-minute periods in a rainfall of 3 inches per hour. Weights of the socks and shoes were obtained initially and at the conclusion of each 30-minute period.
(Provisional Report, 9-10 July 1945)

CHAPTER VIII

DETERMINATION OF MOISTURE DISPOSITION AND UPTAKE

The problem of moisture disposition in clothing and footgear was recognized early in the Laboratory's testing program. Two aspects of the problem were separately considered for practical purposes:

(1) The disposal and dissipation of the moisture from the clothing were studied.

(2) The moisture uptake of the test items was studied and possibilities of control were investigated. This entailed attempts to channel the moisture into the most desirable locations.

The first test determined the moisture uptake of rubber boots:

Seven subjects were in the Cold Room wearing rubber boots, knee length at an exposure temperature of plus 20°F. The subjects walked for 6 miles during a 3-hour exposure period and rested the remainder of the time. Our chief interest was knowledge concerning the amount of moisture accumulation from sweating as a result of the wearing of the boot. Socks and boots were weighed before and after use.

(Provisional Report, 3 July 1943)

Subsequent tests of other items employed the same procedure. One test which investigated the uptake of clothing in rain is described in the following excerpt:

The dry weight and moisture uptake of three uniform assemblies for use in Zone III have been determined. Moisture uptake was measured under two conditions. In the first experiment, soldiers stood for at least 30 minutes in a drenching rain in the Jungle Room. It has been estimated that the water output was equivalent to approximately 2 inches of rain per hour. Thus, the exposure was comparable to at least 1 inch of rainfall. The subject received no protection from the water except that offered by the clothing enumerated in the three assemblies under Test Items. Raincoat, ponchos, etc., were not used. The only item in the assembly that is relatively water-repellent is the field jacket, M-1943.

This first experiment was planned to simulate a soldier fully clothed standing in a heavy rain. Under certain circumstances, however, such as wading streams or sleeping in wet foxholes, soldiers would be confronted with water entering and completely soaking the clothes from within outward as well as the reverse. If this should occur in humid weather when the sun or other means of drying the clothes were not available, then the only step that could be taken would be to remove the clothes, wring them as dry as possible, and put them on again.

In order to study the moisture uptake that would occur in such a situation a second experiment was performed. The clothes were soaked for 30 minutes in a tub of water, allowed to drain for 2 minutes, weighed, wrung out and reweighed. In this manner the maximum possible moisture uptake was obtained.
(Provisional Report, 26 April 1944)

With the acquisition of the Cold-Room treadmill, a new phase of the moisture-uptake problem could be studied. By utilizing the treadmill, controlled exercise could be included in the test and various degrees of moisture uptake produced. An example of this type of test follows:

Eight soldiers participated in the exercise experiments. The ambient temperature in the Cold Room was plus 20°F. Each man marched on the motor driven treadmill for 1 hour at a speed of 3.5 mph. on 2 successive days. In addition to the Basic Items, overpants were worn on one test day and Trousers, Field, Cotton were worn on the alternate day. The soldiers carried a 40-pound load fastened to a plywood packboard during each march. Each item of clothing worn below the waist (except boots) was weighed prior to and at the conclusion of the period on the treadmill. The soldiers had to leave the Cold Room in order to have the clothing weighed following exercise. The clothing was removed, weighed and replaced as rapidly as possible, and the subjects re-entered the Cold Room wearing the same clothing worn during exercise and remained at rest until unbearably cold. Tolerance times and skin temperatures were recorded in the usual manner.
(Provisional Report, 4 August 1944)

Other items tested by the Laboratory required special techniques: for example, the following procedures were devised for handgear testing:

There are three phases of the moisture uptake and penetration study of experimental shells considered in this report. These are: (a) the mittens worn by soldiers were exposed to a fine spray; (b) the mittens on wooden forms were exposed to heavy artificial rainfall; and (c) mittens worn by soldiers while handling damp objects, respectively.

In the first phase the mittened hands were placed through holes in a board wall (forming a stockade) into a fine spray of water. The hands were turned every 15 minutes to give equal exposure to palms and backs. The moisture uptake for each insert and shell was measured at the end of approximately 90 minutes. No significant statistical differences can be detected in the moisture uptake of the inserts, and it is believed that a large percentage of the moisture, if not all of it was derived from the insensible sweat loss by the soldier.

In the next phase, data were obtained on the performance of the shells in rains of varying intensity. The shells containing inserts were placed on wooden forms so that the mittens could be exposed to the rain at a 45° angle.....Again, there is an almost imperceptible gain by the inserts, practically all of which is believed to have come from difficulties involved in taking the inserts from the shells without some moisture transfer. As shown before, the pile backed shell took up more moisture than any other type. [The moisture gain obtained] when only the backs of the gloves were exposed to 30 inches of rain.....is still extremely small in proportion to the total gain of the shells and there are no significant differences between the inserts covered by different types of shells. It is significant that the moisture gain of the shells is only slightly higher under the more rigorous conditions of the second test.

The tests described up to this point involved no active use of the mittens and it is reasonable to conclude that while the hands remain inactive, good protection from water is provided. Therefore, additional tests were planned and executed which would simulate the use of the items in activity. A steel cylinder, measuring 2 1/8 inches in diameter by 9 3/8 inches in length and weighing 10.5 pounds, was wrapped in a wet towel and carried by the soldiers with their palms up for three periods of 10 minutes each. Before each period the towel was soaked with water.....Inspection of the mittens showed that most of the leakage appeared to be



TESTS FOR MOISTURE DISPOSITION AND UPTAKE

at the seams of the shell. Of interest is the fact that only the cloth backed shells showed this leakage although the limited number of observations precludes attaching any great significance to this observation.....

Finally, a wet towel was wrung out ten times by each soldier while wearing mittens, care being taken at all times to provide as equal pressure as possible on both hands.

(Provisional Report, 5 June 1944)

The study of moisture disposition in footgear conformed to standard procedures which are described as follows:

For the third phase wet sockgear was worn with an exposure temperature of plus 20°F. in order to determine the moisture disposition qualities of the two types of footgear. The weights of the sockgear were obtained when dry, after being soaked with their own weight of water, and after the exposures. Inasmuch as different sockgear assemblies were used, it is advisable to use percentages rather than absolute values. Following is a summary of the data.....

	German Boot	Shoepac
Moisture lost from sockgear percent of total added	23.5	19.7
Moisture taken up by boot, percent of total added to sockgear	14.4	10.6
Net loss from assembly, percent of total added to sockgear	9.1	9.0
Moisture remaining in sockgear, percent of total added	76.5	80.3

(Provisional Report, 31 March 1945)

The effect of the all-rubber and fusion linings in the Type 405-9 and 405-10 shoepacs as compared to the fabric lining of the standard shoepac was studied during two 7-mile marches. For the morning march, eleven men wore wet sockgear inside a 405-9 shoepac on one foot and a 405-10 shoepac on the other. Sockgear, insoles and boots were weighed before and after the march. (Provisional Report, 6-7 April 1945)

CHAPTER IX

PHYSICAL MEASUREMENTS OF MILITARY CHARACTERISTICS

Numerous test items received at the Laboratory were not subjected to physiological test procedures. Three principle reasons for this alteration in method were:

(1) Some items possessed inherent characteristics which were not adaptable to physiological test methods. Gasoline stoves, cigarette lighters, and tents were included in this group.

(2) The information desired could not be collected by physiological methods. For instance, information relating to the ability of an item to withstand cold temperatures required physical testing.

(3) Substitution of physical tests for physiological tests afforded greater ease in controlling and recognizing variables. The tent experiments described in this chapter provide an example of this variation in procedure.

No logical sequence of development is apparent in the physical-test procedures; in most instances, the tests did not require complicated techniques which could be refined. Therefore, this presentation of the physical test methods is arranged according to the type of test instead of according to chronological development.

Tents

In tent testing, the ability of the tent to dispose of moisture was emphasized. The following test was designed to provide such information:

Two each of the Nylon tents were placed in the Cold Room at minus 40°F. A tin of water of approximately 500 grams was allowed to boil in the tent over a 6-hour period. The amount of water was calculated to be the amount (250 grams) that would be lost in vapor by two

men sleeping in the tent for 8 hours plus an additional 250 grams that would be added by vapor during the preparation of a light evening meal and a breakfast. During the day, all of the inclosures were tightly sealed in order that all of the vapor would condense on the inside walls of the tent. At the end of the exposure, the tent was opened up and the inside inspected. It was then shaken vigorously rather than brushed off with a brush. Some snow had collected on the outside of the tent during the day and this was brushed off. The tents were weighed before and after the Cold Room experiment. On the second day, the four tents were placed in the Cold Room, with two men and one man, respectively, in sleeping bags in one of each of the two kinds. In addition, a standard 2-man mountain tent (941.1) and a 2-man mountain tent of same design, but made of shelter-half duck (E-941.6) were placed between the coils. In these two tents tins of water were heated. The temperature in the room was minus 40°F., and between the coils was about minus 50°F. The subjects remained in the tents for 6 hours, after which time frost and snow was removed as before. Weights were taken before and after the exposure.

(Provisional Report, 15 October 1943)

The technique described above was modified in an effort to collect additional data relating to the thermal insulation characteristics of the tent.

This is described as follows:

The tent was erected in the Cold Room with the camouflage cover on the outside. The exposure temperature was slightly below minus 25°F. The tent was weighed before and after use. Two Alladin stoves plus two observers were in the tent the greater part of the exposure period. These were the only sources of heat. During the entire period there was 1340 cc of gasoline consumed by the stoves, which should have given off more than 10,000 Calories of heat. The two observers contributed an additional 900 Calories. In addition to the vapor contributed by the observers, 1094 cc of water was evaporated on the stoves. Gas samples were taken at hourly intervals during the period for determination of oxygen, carbon dioxide and carbon monoxide content. Twelve thermocouples were placed at various regions in relation to the tent, both inside and outside of it.....

- (1) Outside of tent on the floor of the Cold Room
 - (2) Outside of the tent about 8 feet above the floor
 - (3) Outside of the tent about 12 feet above the floor
 - (4) On the outside wall of the tent at snow level
 - (5) Inside of tent on the floor in the center
 - (6) One foot above the tent floor in the center of tent
 - (7) Four feet above the floor in the center of the tent
 - (8) Inside of tent 18 inches below the peak
 - (9) At the peak of tent, inside
 - (10) Outside of tent on the outer cover
 - (11) Inside of tent on the floor at the periphery
 - (12) One foot above this position
- (Provisional Report, 1 November 1943)

Solid Fuels

Solid fuels were frequently investigated at this laboratory. A standardized procedure for determining the heat output of the fuels was developed after a few problems had been encountered and solved. An account of one such problem follows:

The test directive concerning solid fuels specified that the basic item in all studies was to consist of the 10-in-1 ration. Unfortunately, it was impossible to meet this requirement. No 10-in-1 ration is available in this laboratory. Cans of a size equal to those found in the 10-in-1 ration (2 or 2 1/2) were available, but they were much too large to be fitted into the usual canteen cup, nor could the meat component of C Ration be heated in the cup. In fact, the only can in the kitchen that would fit in the cup was a 6-ounce can.

Because of these difficulties water was used as the basic item in all tests. This substance possessed the desirable feature of availability. Since its specific heat and heat of vaporization are known and constant, precise calculations of the amount of heat delivered by the various fuels could be readily made.

This allowed a more accurate comparison of one fuel with another. The data are expressed in a standard unit rather than 'the change of temperature of a can of meat and beans.' In all instances 500 cc of water and the standard canteen cup were the basic items. In calculating the number of calories taken up by the water the change in temperature of the water and the amount vaporized were both considered.

(Provisional Report, 16 March 1944)

A complete account of the procedure used in determining the heat output appeared soon after the above report. It follows:

During the early part of the testing period, experimental techniques were not standardized as they are at present. It was not until the conclusion of the studies of the effect of variation of the position of the cup in the stove and of the distance between the bottom of the cup and the fuel, that a standardized technique was evolved. Since then the technique has been maintained rigidly. It may be described as follows:

(1) The canteen cup is pushed as far into the stove as possible, i.e., $1 \frac{5}{8}$ inches.

(2) The distance between the top of the fuel and the bottom of the cup is always 2 inches at the beginning of the experiment. As the fuel is consumed the distance increases to a greater or lesser extent in all fuels except No. 9.

(3) The basic item to be heated has been 500 cc of water. This is sufficient to fill the canteen cup about two-thirds full.

(4) Measurements obtained are: (a) the length of time the fuel burns; (b) the quantity of the fuel consumed; (c) the change in temperature of the water; and (d) the amount of water evaporated during the test.

(5) From these data it is possible to calculate the heat delivery of the fuels in Calories/gram and Calories/minute.

(6) A further calculation has been made for those fuels with noncombustible containers. In addition to the calculation of Calories/gram and Calories/minute based upon the weight of fuel consumed, it was felt desirable to consider the weight of the container also.

Accordingly, the weight of the empty container was determined and in the calculation that fraction of the weight of the container proportional to the fraction of the total fuel used was added to the weight of fuel. This value was then taken as the number of grams in calculating the delivery of 'Calories/gram with container considered."

(Provisional Report, 12 May 1944)

One phase of the solid fuel study, the luminosity of the flame, was not investigated until the Fall of 1944. The method utilized to determine the degree of luminosity was described as follows:

Despite the importance attached to evaluation of luminosity this laboratory has been unable to offer any other than a subjective rating of its intensity up to the present time. Flames have been classified as being non-luminous, moderately luminous, or highly luminous. However, the recent acquisition of a Weston Phototronic Cell equipped with a Viscor Filter has enabled accurate measurement of the intensity of the visible light emitted during combustion of the solid fuels. The Viscor Filter is of definite value in any work of this kind since it absorbs a majority of the longer and shorter wave lengths of light to which the human retina is not sensitive. Therefore, only visible light plays a role in the activation of the cell.

It must be realized that while this arrangement is very desirable in that it gives a relatively accurate measure of the intensity of the light source in foot candles, it does not allow a completely accurate appraisal of the visibility of the light source under battle conditions. In the measurement of the foot candle power of a light source no consideration is given to the predominant wave length emitted. The transmission of light is affected by the wave lengths of which it is composed and their relative predominance. A spectrophotometer is necessary to obtain such data. It is, therefore, apparent that this technique does not give a complete picture. Nevertheless, it represents an advance over purely subjective ratings as to the luminosity of the flames in providing a definite physical reading which allows closer and more accurate rating of the fuels in regard to luminosity.

All the readings given in this report were taken in complete darkness. A photographic dark room was used.

The Weston Phototronic Cell was fixed on a plane level with the flame of the solid fuel and at a constant distance, 6 inches, from it. The current produced by impingement of the light on the cell was measured by means of a microammeter. A flashlight was required to read this, but the access of stray light to the cell was prevented by suitably placed black baffling. The intensity of light emitted from all fuels was measured using both a light and a dark background.

(Provisional Report, 25 November 1944)

Gasoline Stoves

Testing of stoves was based upon the techniques employed in testing solid fuels. The first attempt resembled slightly the standard procedure and is included for purposes of comparison:

The British experimental stove was compared with a late model Coleman stove at room temperature and at sub-zero temperature in the Cold Room. (The stove was used with and without a conical metal skirt 2 1/2 inches deep by 8 1/2 inches at the larger end). At room temperature 550 cc of water was boiled away in approximately 40 minutes by either stove. The same container was used for both experiments and the stoves were on full. These experiments were conducted under ideal conditions and no significant difference in efficiency was noted.

(Provisional Report, 29 December 1943)

The standard procedure is described in the following excerpt from the Provisional Reports:

Tests of the M-1941 and M-1942 stoves have been completed in still air and in a 5 mph. wind at four exposure temperatures in the Cold Room, i.e., plus 30°F., plus 26°F., minus 5°F., and minus 35°F. The test procedure was as follows: The inner container of the mountain cookset was filled with 1000 grams of water and heated from a temperature slightly above freezing for 7 to 10 minutes. The limiting factor in time was the avoidance of boiling the water. In still air the length of the run was, on most occasions, 8 minutes while in the 5 mph. wind 10 minutes was arbitrarily used although a longer length of time would have been needed in all cases to raise the temperature of the water to a point near boiling. By reduction of the values to kilogram-calories per minute the results of any two runs were comparable. Temperatures were obtained by the thermocouples inserted through rubber stoppers placed in the

lids in such a manner that the thermocouple was a uniform distance from the bottoms of the containers. Temperatures and weights of the water were taken at the beginning of each run and at the conclusion. The kilogram (large) calories were calculated by the following equation:

$$\text{kg. cal.} = \frac{\text{mass of water heated (in grams)} \times \text{temp. rise in } ^\circ\text{C.}}{1000} \\ + \frac{(\text{gms. of water evaporated} \times \text{heat of vaporization})}{1000}$$

It should be noted that the testing is largely a performance phenomenon; in no other way can the variations from stove to stove of the same type and under the same conditions of wind and temperature be satisfactorily explained. Individual performances can be and are affected by such things as dirty generators, clogged jets, leaks at base of generator and at point at which the stove itself screws into gas tank, and differences in air pressure. An attempt was made to keep each stove at maximum performance for each run and the amount of time and effort necessary to attain this condition is one subjective index to the efficiency of the stove.

(Provisional Report, 1-2 November 1944)

Effect of Environmental Conditions

With test chambers capable of producing a variety of climatic conditions, this laboratory possessed the equipment required for determination of the effect of environmental conditions upon test items. No specified procedure was utilized. Testing ranged from the observation of the effect of heat or cold when the item remained static to rigorous physical tests designed to provide severe test conditions. A few excerpts from the Provisional Reports describe the methods of testing:

One pair each of shoepacs and blucher boots were tested. The uppers of one shoe of each pair (Boot B), had been stuffed with oil which was reported not to harden at temperatures as low as minus 30°F. The other boot of each pair (Boot A), received no special treatment. It was requested that the boots be left in the

Cold Room for at least 48 hours at temperatures as low as minus 30°F.

(Daily Report, 12 October 1943)

The pads were tested for pliability, flexibility and general resistance to cold at temperatures of plus 30°F., minus 10°F., and minus 40°F., respectively. The deflated pads were placed in the Cold Room for 30 minutes prior to test; they were then inflated and kept so for the next 30 minutes. Pads were then deflated, rolled and folded into a bundle measuring approximately 15" x 15" x 5", and packed into a Pack, Field, M-1943. This last procedure was repeated 5 times, the pad being handled and treated rather roughly with the hands each time the folding and unfolding took place. This was to simulate speedy deflation and packing such as might be required in the field. At the conclusion of the test all pads were inflated and tested for leaks by immersion in water. (Provisional Report, 17 November 1944)

The experimental item, Suspenders, Trousers, Neoprene has been subjected to three tests to determine the advisability of substituting it for the standard suspenders. These tests were as follows:

(a) Stretch tests at room temperature and at minus 20°F. to determine the effect of subzero temperatures upon the elasticity of the neoprene.

(b) Breakage tests of suspenders which had been exposed to subzero temperatures for varying periods of time.

(c) Tests in which the suspenders were worn by test subjects and from which subjective information was obtained regarding the suitability of both types of suspenders.

The elasticity of the neoprene suspenders was determined by measuring a given length of suspender (the same length for each test) and then re-measuring this length as 500 gram weights were added. This procedure was conducted at room temperature and then repeated at minus 20°F. on four different lengths of material.

The breakage tests were conducted on fabric which was: (1) unexposed to the Cold Room, (2) which was exposed at temperatures ranging from minus 20°F. to minus 40°F. for 12 hours, and (3) which was exposed at each temperature for 72 hours. A standard Scott Tester was used for this test.

(Provisional Report, 14 July 1945)

Before manipulative testing of the Bags, Water-proof, Special Purpose, was started, blanket rolls were packed in each bag to give it the shape and bulk which it would have if radio equipment were placed in it. At each test an effort was made to open and close the bags in a similar and a reproducible manner so that the throat of each would receive a comparable amount of folding, twisting, stretching and wrinkling. The bags were folded and unfolded completely, a total of 10 times in each test.

The bags were first tested in the All Weather Chamber at plus 83°F., after being conditioned for 12 hours. The relative humidity was approximately 70 percent. At this temperature the Natural Rubber and Buna S seemed equally flexible and slightly more flexible than the Neoprene.

The bags were next tested in the Cold Room at plus 30°F., after they had been conditioned for 36 hours at temperatures ranging from 0°F. up to plus 30°F. The Natural Rubber seemed to have lost none of its flexibility. The Buna S and the Neoprene appeared only a little less flexible than the Natural Rubber, with the Buna S being slightly the more flexible of the two.

After 4 hours conditioning at 0°F., the procedure of opening and closing the bags was repeated.

Finally, the bags were left in the Cold Room for 4 days with the temperature hovering around plus 30°F. all of the time. The flexibility of the Natural Rubber seemed little changed after this exposure, the Buna S was still a little less flexible than the Natural Rubber, while the Neoprene was considerably less flexible than either.

(Provisional Report, 25 July 1944)

Compressometer Readings

The Ames Compressometer measures thickness under varying pressures. Thus, for an easily compressible material, such as wool pile, the thickness becomes lower as the pressure is increased. The relative compressibility of two types of material, therefore, can be readily determined by plotting the thickness of each under various pressures and comparing the slopes of the curves. This phase of physical testing is important because there is a

recognized correlation between thickness and thermal insulation. All other things being equal, a fabric which retains its thickness well is probably a good insulator.

Compressometer studies of the thickness of the various types of pile were carried out on the Ames Compressometer. The technique used in determining the thicknesses consisted in placing a single layer of the fabric pile side down on the base of the apparatus and bringing the 1 inch square foot down until the desired test pressure was reached. The thicknesses of the fabrics under loads of 0.2, 1.0 and 2.0 pounds per square inch are presented. (Provisional Report, 17 February 1944)

Compressometer readings at the heels of the felt and ski socks were obtained at the following stages of testing:

- (1) Initial reading
- (2) After first phase but before first laundering
- (3) After first laundering
- (4) After second phase but before second laundering
- (5) After second laundering
- (6) After third laundering

(Provisional Report, 26-28 March 1945)

Shrinkage

Linear measurements were taken on all jackets prior to laundering and after one and three launderings..... The measurements were taken as directed and are as follows:

(a) Width across back of blades, from outside edge of side seams to outside edge of opposite side seams.

(b) Width across back at center of blades, at the point where the seam of the under-sleeve and top-sleeve join the back arm scye seam.

(c) Width of shoulder point, sleeve and wrist tab added, taken from center seam where knitted neck piece joins center back over shoulder to point of shoulder to end of sleeve where sleeve joins wristlet, thence to end of wristlet.

(d) Length of inside sleeve in usual manner; from arm scye depth to end of sleeve where wristlet joins end of sleeve.

(e) Length of back in usual manner; from center seam at point where knit collar joins back to full length.

(f) Across chest directly under first button when buttoned, lying flat and pulled out to full width from front sleeve seam to opposite front sleeve seam.

(g) Across chest under second button to each side; keep coat in same position as used in measuring point.

(h) Repeat above at button under last button.
(Provisional Report, 23 June 1944)

Moisture Uptake and Drying Rates

In Chapter VIII, the moisture uptake of test items during physiological testing was discussed. The salient difference between physiological and physical moisture-uptake testing can be briefly stated: physical testing is usually concerned with maximum possible moisture uptake, a characteristic which cannot be determined by physiological methods. After determination of maximum moisture uptake, the collection of data relating to drying rates follows in logical sequence. Descriptions of these procedures follow:

(1) Moisture Uptake

In order to obtain data on the total moisture pickup of the gloves, they were filled with water to remove pockets of air and then immersed in a container of water for 30 minutes. During this period of time the gloves were agitated constantly so as to displace any air pockets which may have remained by chance in the fingers. After soaking for 30 minutes the gloves were drained until the dripping had slowed to a minimum and weighed. The gloves were then hung up and allowed to drip for another 30 minutes and reweighed.

(2) Drying Rates

After the gross moisture uptake tests were completed, the gloves were dried in the Garment Conditioning Room at a temperature of 85°F. and 50 percent relative humidity. Weights of the gloves were obtained every 15 minutes throughout the first 4 hours.....It is apparent

that no difference exists in the drying rates as such but that it would have taken a longer time for the napped gloves to dry inasmuch as they had more moisture originally. A projection of the curve indicates that a minimum drying time of slightly over 8 hours for the unnapped and slightly over 10 hours for the napped gloves would have been necessary although the drying rates were practically the same (6.0 grams per hour for the unnapped and 6.8 grams per hour for the napped gloves). (Provisional Report, 19-20 April 1945)

All socks were weighed dry and then soaked in water with a temperature of 38°F. for 20 minutes. The socks were agitated to insure even and maximum uptake. They were then allowed to drain for 30 seconds and weighed wet. After this, all socks were wrung out as completely as possible and reweighed. The sock with no mate and one sock of the three pairs were placed in the Cold Room, the other three paired socks were left in the Laboratory. All socks were weighed each hour for 8 hours, left overnight and then weighed each hour the following day. The Cold Room was at plus 10°F. during the day, and gradually warmed up from plus 10° to plus 30°F. during the night. The experiment was terminated due to the weekly defrosting of the Cold Room. On the following day, the socks were similarly handled and exposed outdoors for 28 hours. Water content was calculated as the percentage increase in weight over the dry weight. (Provisional Report, 24 February 1944)

The maximum moisture uptake of felt socks (1 pair) and wool ski socks (1 pair) was determined by soaking the socks in water and actively agitating them until no more water could be taken up. The socks were resoaked and reweighed until a maximum gain had been established. This required only four soakings before a maximum water gain had been established. The socks were allowed to drain for 30 seconds prior to the final weighing soaked. The mean values for 2 pair of each type of socks are:

	Felt Sock	Ski Sock
	grams	grams
Dry Weight	90	80
Soaking Wet Weight	415	455
Water Uptake	325	375
Water Gained per 100 Grams of Dry Sock	361.1	468.8

The amount of water taken up by felt socks and ski socks when passively soaked under water for 30 minutes was determined next. Under these circumstances the socks took up slightly less water than when the socks were wrung out repeatedly and agitated under water.

The drying rates of felt socks and ski socks which were equally wet were determined by weighing the socks at intervals. Both types of socks were practically dry in 24 hours under laboratory conditions, i.e., without exposure to direct sun and wind.....there is little practical difference in the drying characteristics of the two types of sockgear although the felt sock had a slightly slower rate.

The water taken up by a felt sock and by a ski sock due to capillary attraction was determined by suspending both types of socks from a rack so that 3 inches of the toe of each sock was under water. The toes were weighted to keep them submerged. The socks were left in water for 2 hours. Inspection of the socks revealed the ski socks to be wet more than twice as far above the water level as the felt socks.

Finally, the rate at which water may be evaporated through either the felt sock or the ski sock was determined by placing 250 cc. beakers (internal diameter, 1.5 inches) covered with a felt sock and ski sock, respectively, in an oven maintained at 140°F. Water evaporated from each beaker, through each type of sock, at a rate of 6 cc. per hour. There was no difference between the rate of water transfer through the two types of socks although both types of socks did slow the rate of water vapor passage, since an uncovered beaker lost water 4 times as fast under the same conditions.
(Provisional Report, 14 August 1944)

During the past week moisture studies on footgear continued. Seven types of boots were studied in the Laboratory in regard to moisture pick-up and rate of drying. The boot for the right foot was filled with wet ski socks, and allowed to stand overnight. The rate of drying after this period of exposure was studied. This was done in order to duplicate entrance of moisture into the body of the boot such as might occur following wear for approximately 1 day with mild exercise. The wet socks were removed before the second weighing. The boot for the left foot was immersed for 1 hour in water. Care was taken to allow no water to enter above the tongue or top of the boot. Any water that leaked in

was emptied out before the second weight was taken. By this procedure it was assumed that conditions comparable to wading in water could be duplicated. The following boots were included in this test: Mountain Ski Boot, plain sole, Overboot, Cloth Overshoe, Shoepac, Service Shoe I, Mukluk and Felt Boot. The mukluk and felt boot were included because in Arctic regions sea water and glacier water may be encountered. The boots were allowed to dry in the laboratory at room temperature.
(Daily Report, 9 October 1943)

Sizing Studies

A sizing study has been conducted in order to determine whether the Bag, Sleeping, Mountain is large enough for men fully dressed as well as for men wearing only wool underwear and socks. Forty-two officers and enlisted men were fitted into the Bag, Sleeping, Mountain, regular size, while wearing 50-50 underwear and 1 pair of ski socks and while wearing the clothing listed under Basic Items. The length and width of the bag were checked to determine their adequacy and each occupant was questioned concerning the location of the face opening. Those men who did not consider the regular sized bag sufficiently large were placed in the large size bag. The height, weight, and surface area of each soldier was measured in order to determine whether any definite relationship could be established between the size of the occupant and the adequacy of the various sized bags. All studies were conducted at room temperature and adequacy of the bags for thermal insulation was not determined.

(Provisional Report, 22 April 1944)

One observer made all of the measurements on the cubic volumes. An attempt was made to have the observer use approximately the same degree of compression each time that the bag was rolled. No claim is made for small differences but it is believed that the large differences are significant. All of the bags that had been used, laundered and used again showed nearly a 50 percent gross reduction in volume over the initial value.

(Daily Report, 30 October 1943)

Insulated Food Containers

Each container was tested at 0° and minus 40°F. For all tests the containers were filled with water at approximately 180°F., without preheating, and temperature readings of the center of the water-mass were taken at regular intervals. Selected cooling curves are presented.

(Provisional Report, 5 October 1944)

Cigarette Lighters

The following excerpts taken from Report No. 145, "Lighters, Individual" are included as an example of a comprehensive investigation as well as a description of testing techniques:

Experiments were conducted in the Physics Laboratory and All Weather Chamber to determine the effect of humid conditions and adverse usage on the operating characteristics and material of each type of lighter. The test items were exposed for 1 week to an ambient temperature of plus 90°F. and a relative humidity of 85 percent; said conditions having been accepted arbitrarily as representing those of the average jungle environment in the Southwest Pacific. In addition, the items were submerged continuously in fresh water for 3 days, and buried in various mixtures of sand, dirt and mud. An appraisal was made after each exposure in regard to the effect on mechanical operation, deterioration of component materials, and ease of reconditioning to a useful state.

The test items were immersed in fresh water in the Physics Laboratory and allowed to remain undisturbed for 3 days. Cases, fuel caps, and wick-snuffers were removed or opened to insure complete saturation of all parts of the lighters. After removal from the water, the lighters were returned to usefulness. Observations were made on ease of reconditioning and effect on materials.

Ease of Maintenance

Troops in the field should not be burdened with carrying special tools or taking time to acquire them for the purpose of performing the simple maintenance functions of replacing flint, wick, and cotton packing. Fueling should be simple and not require a special tool. In this aspect of the test the lighters were investigated in regard to ease of maintenance, tools necessary for maintenance, and danger of losing parts during maintenance operations. Two soldiers familiar with the lighters replaced flints, wicks, and cotton packings in four samples of each type of test item. These operations were timed and observations were made in regard to the minimum number and types of tools needed, and the loose parts which might become lost during the operation. In addition, the ease of fueling each of the test items

with various commercial lighter fluid containers, glass tumblers, bottles, empty C Ration cans, and by immersion in cans of gasoline was noted.

Effect of Environmental Temperature and Humidity Upon Performance.

Two series of experiments dealing with comparative reliability of ignition and desirable length of burning time on one ignition were performed. These were conducted in the Physics Laboratory, Constant Temperature Room, All Weather Chamber and Cold Room, respectively. In the Physics Laboratory the temperature was plus 75°F., and the relative humidity was approximately 30 percent. Temperatures of plus 100°F. and plus 110°F., with relative humidities of 32 and 30 percent, respectively, were maintained in the Constant Temperature Room. In the All Weather Chamber the temperature was plus 91°F.; the relative humidity was 84 percent. Temperatures of plus 30°F. plus 10°F., 0°F., minus 20°F. and minus 45°F. were provided in the Cold Room. In the first series of experiments the number of ignitions resulting from ten attempts was determined. The word attempt is used to indicate one single operation of the firing mechanism. In the second phase, the lighters were expected to ignite a wood kindling fire, a gasoline stove (1 burner, M-1941) and solid fuels, Types No. 1 ("Fuel, Solid, Candle, Modified"), No. 2 ("Hot Box"), No. 3 ("Trioxane"), and No. 5-A ("Sterno"), respectively.

Resistance to Wind

This Laboratory considered it desirable to set up an arbitrary standard of performance for the lighters in regard to wind resistance. It was assumed that a satisfactory item should ignite and stay lighted for at least 5 seconds in a 6 mph. wind without any protection other than that provided by the lighter itself. A burning time of this duration would be required to light a cigarette. For lighting a wood fire, gasoline stove, or solid fuel, an average burning time of 30 seconds in a 6 mph. wind was estimated to be necessary. Experiments were conducted in the wind tunnel at room temperature in order to determine the effect of various wind velocities on the operation of the lighters. For this phase of the test each lighter, using the various fuels, was ignited in the wind tunnel with wind velocities varying from 1 to 16 mph.

Duration of Fill

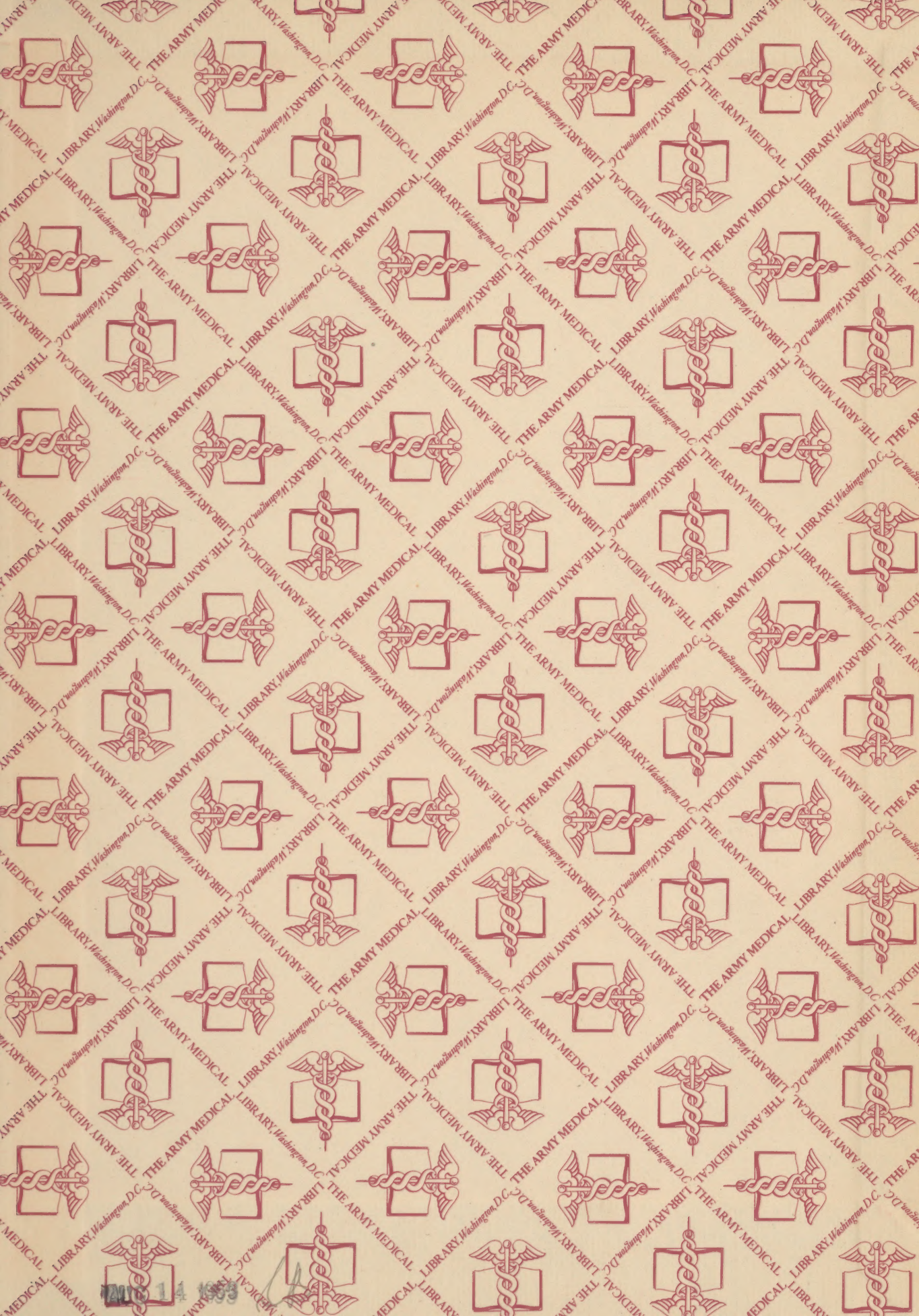
The total burning time of a lighter on one fueling is a highly variable function controlled by factors such as quantity of filling, evaporative loss, wick exposure, compactness of packing, and conditions under which the lighter is operated. Experiments were conducted at room temperature in the Physics Laboratory in order to determine the duration of fill of the lighters with each of the four fuels. Each wick was exposed 1/8 inch and the cotton packing in each type of test item was tamped to approximately the same density. The lighters were ignited and allowed to burn for periods of from 1/2 to 4 minutes until they failed to ignite due to exhaustion of the fuel supply. Four minutes was (sic) taken as the maximum burning period because of the danger of overheating the lighters.

Rate of Fuel Evaporation

Total fuel evaporation from the various types of test items when fueled and left unused for one week was determined at room temperature in the Physics Laboratory, in the Constant Temperature Room and in the Cold Room. The temperature in the Physics Laboratory was 75°F. A temperature of 94°F. was maintained in the Constant Temperature Room, while temperatures of from 0°F. to plus 10°F. prevailed in the Cold Room. The lighters were weighed empty. After fueling each was reweighed to determine quantity of fuel added. The test items were placed in the test chambers and were not molested for one week, except for determination of their weight once each 24 hours.

Efficiency Characteristics

Efficiency characteristics of the various types of lighters were investigated in the Physics Laboratory in the All Weather Chamber, and in the Cold Room. Temperatures of plus 90°F. in the All Weather Chamber, and 0°F. in the Cold Room were used. The temperature in the Physics Laboratory was approximately 75°F. For this phase of the test, a simulated typical day's operation of a military lighter was established. It was assumed that a lighter would be required to ignite an average of 17 cigarettes and 4 fires or solid fuels a day during field use. Burning time of 5 seconds for cigarettes and 20 seconds for fires and solid fuels were used in the estimate. The ignitions were staggered at irregular intervals on a 16-hour period; after which the lighters were allowed to remain unused for 8 hours.



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